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TRAINING SITUATION ANALYSIS FOR FLIGHTLINE MAINTENANCE TRAINING: IMPLICATIONS FOR IMIS

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This report is the first part of a project to evaluate how the Integrated Maintenance Information System (IMIS) can be used in aircraft maintenance training. The report presents the results of a Training Situation Analysis, in which the current Air Force maintenance training environment was analyzed and hypotheses were developed about how IMIS may affect maintenance training. Furthermore, in order to develop hypotheses about IMIS's effect on training, the Air Force maintenance process and IMIS's capabilities were also investigated. In performing the Training Situation Analysis, structured interviews were conducted at Air Force maintenance and maintenance training facilities, including Technical School Field Training Detachment, Logistics Support Training, and on-the-job training sites. Additional data were collected through literature reviews and observations of IMIS demonstrations. The data suggested that maintenance technicians need training in 1) a variety of maintenance procedures, and 2) the problem-solving skills needed to handle troubleshooting problems that are not solvable by standardized procedures (e.g., technical orders). Current training to provide this problem-solving knowledge needs considerable improvement.

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LIST OF ACRONYMS

AF	-	Air Force
AFS	-	Air Force Specialty
AFSC	-	Air Force Specialty Code
AI	-	Artificial Intelligence
ANG	-	Air National Guard
APS	-	Authoring and Presentation System
CAMS	-	Core Automated Maintenance System
CDM	-	Content Data Model
DM	-	Diagnostics Module
FCR	-	Fire Control Radar
FI	-	Fault Isolation
FTD	-	Field Training Detachment
HUD	-	Head-Up Display
IMIS	-	Integrated Maintenance Information System
ITS	-	Intelligent Tutoring System
LRU	-	Line Replaceable Unit
LST	-	Logistics Support Training
OJT	-	On-the-Job-Training
OSR	-	Occupational Survey Report
PMA	-	Portable Maintenance Aid
POI	-	Plan Of Instruction
STS	-	Specialty Training Standard
TD	-	Task Difficulty
TE	-	Training Emphasis
TO	-	Technical Order

SUMMARY

This report is the first part of a project to evaluate how the Integrated Maintenance Information System (IMIS) can be used in aircraft maintenance training. The report presents the results of a Training Situation Analysis, in which the current Air Force maintenance training environment was analyzed and hypotheses were developed about how IMIS may affect maintenance training. In order to develop hypotheses about IMIS's effect on training, the Air Force maintenance process and IMIS's capabilities were also investigated.

In performing the Training Situation Analysis, structured interviews were conducted at Air Force maintenance and maintenance training facilities, including Technical School, Field Training Detachment, Logistics Support Training, and on-the-job-training sites. Additional data were collected through literature reviews and observations of IMIS demonstrations.

The data suggested that maintenance technicians need training in 1) a variety of maintenance procedures, and 2) the problem-solving skills needed to handle troubleshooting problems that are not solvable by standardized procedures (e.g., technical orders (TOs)). Troubleshooting problems that require problem-solving knowledge beyond that in the TOs are fairly common in the Air Force maintenance environment. Current training to provide this problem-solving knowledge needs considerable improvement. IMIS can help provide an effective solution to this training problem. Research suggests that IMIS can be used most efficiently as a simulator in which the intelligence and knowledge of the IMIS Diagnostic Module is used to provide coaching and practice on troubleshooting problems.

Part two of this research project entails a demonstration of some of the training capabilities of IMIS discussed in this report. This demonstration will make use of the IMIS Portable Maintenance Aid and other components to enhance training of Air Force maintenance technicians.

TRAINING SITUATION ANALYSIS FOR FLIGHTLINE MAINTENANCE TRAINING: IMPLICATIONS FOR IMIS

I. INTRODUCTION

The Air Force Armstrong Laboratory is conducting research to develop and demonstrate a prototype Integrated Maintenance Information System (IMIS). IMIS is a job aid that will help technicians in many aspects of maintenance activities. The prototype IMIS will allow access to, and integration of, information for such activities as flight debriefing, opening and closing work orders, interactive diagnostics, review of technical manuals, parts ordering, automatic maintenance data collection, and tracking aircraft status. These automated capabilities are expected to greatly improve the way flightline maintenance technicians perform their jobs. IMIS is currently being developed for maintenance of the Air Force's F-16, F-22, and Navy's F/A-18 aircraft.

While the potential of IMIS as a viable job aid has long been recognized, the concept of using IMIS to effectively present training has only begun to be explored (Babiarz, Jernigan & Gumienny, 1989; Brandt, Jernigan & Dierker, 1987). Mei Technology Corporation, under contract to the Air Force Armstrong Laboratory, Human Resources Directorate, undertook a research effort to determine whether IMIS holds promise for training, what specific instructional activities can best make use of IMIS' capabilities, and what changes, if any, are necessary to allow IMIS to fully implement a training function. This report describes the first of several major steps taken in analyzing IMIS training capabilities -- conducting a Training Situation Analysis for maintenance training. Our main goals in this report were to (1) assess the current Air Force maintenance training situation and establish a baseline for further research, and (2) develop hypotheses about the effect IMIS will have on maintenance training. However, in order to understand IMIS's effect on training, information was needed on more than the current training situation. We also needed to understand the nature of the Air Force maintenance process itself, since planning computer-based training for a task requires detailed knowledge of how that task is performed. In addition, we had to obtain information about IMIS's capabilities. Therefore, in addition to investigating the current training situation, we also gathered data on the maintenance process and IMIS's capabilities.

Scope

Establishing a maintenance training baseline was necessary to determine how the application of IMIS could increase the effectiveness of both on-the-job and classroom training. Therefore, in addition to studying on-the-job training (OJT) practices at operational Air Force bases, we investigated maintenance training practices at Technical Training Centers (Technical Schools), where new airmen report after basic training, and Field Training Detachments (FTDs), where additional maintenance-related training is provided at operational bases.

Our analysis centered on information relating to maintenance of five F-16 sub-systems, namely, the Fire Control Radar, Hydraulic Power Supply, Heads-Up Display, Cabin Pressurization System, and Inertial Navigating System. These five sub-systems were previously

selected by the Armstrong Laboratory as part of the IMIS prototype system development. The analysis considered such factors as the specific tasks trained, who conducts the training, how training takes place, the duration of training, how individual training accomplishments are recorded, and trainee reliance on job aids of various kinds, in particular the technical orders (TOs) and other documentation. In other words, we attempted to provide a representative description of current practices in OJT and during formal training in the Technical Schools and FTD classrooms.

In the remainder of this report, we first describe the methodology used for the Training Situation Analysis, then summarize some important findings from a literature review of maintenance and maintenance training issues. These findings are used in interpreting the data from the Training Situation Analysis. Following this, results of the Training Situation Analysis are presented in three sections, focusing on IMIS's capabilities, the Air Force maintenance environment, and the Air Force maintenance training environment. Finally, we develop and describe hypotheses about how IMIS may affect maintenance training.

II. METHODOLOGY

Observations of IMIS

To gather data on IMIS's capabilities, we followed a three-step process consisting of: a literature review of all IMIS components; briefings and direct observation of an F/A-18 IMIS component demonstration at the Marine Corps Air Station, Beaufort, SC; and meetings with IMIS experts at Wright-Patterson AFB, OH. This information was used in developing hypotheses as to how IMIS could be used to improve or supplement current Air Force training.

First, technical reports were reviewed for general information concerning various components of IMIS such as the Portable Maintenance Aid (PMA), Authoring and Presentation System (APS), Content Data Model (CDM), Diagnostics Module (DM), and the Maintenance Workstation. We obtained information on IMIS from a number of reports (Babiarz, et al., 1989; Brandt, et al., 1987; Link, Von Holle, & Mason, 1987; Cooke, Jernigan, Huntington, Myers, Gumienny, & Maiorana, 1990; Cooke, Jernigan, Maiorana, & Myers, 1990; Cooke, Jernigan, Myers, & Maiorana, 1990; Cooke, Maiorana, Myers, & Jernigan, 1991; Earl, Gunning, Freese, Shroder, Werts, & Reser, 1990; Link, Murphy, Carlson, Thomas, Brown, & Joyce, 1990). These reports contain considerable information about IMIS, but do not describe the details of the most recent versions of IMIS. However, the reports provided the analysts with a knowledge base that could then be enhanced through observations of the various IMIS components.

Later, through meetings with Logistics Research Division personnel at Wright-Patterson AFB, analysts clarified any questions concerning the various components of IMIS, how they operate together, and ways in which they might affect the Air Force maintenance community. Although these meetings and observations yielded valuable information, certain issues arose. In particular, at the time of our site visits, the APS and the PMA for the F-16 were still being developed and revised. Analysts viewed the F/A-18 PMA and APS in use during observations at the Marine Corps Air Station, Beaufort, SC and Wright-Patterson AFB, OH respectively. Unlike

the F/A-18, the APS for the F-16 is expected to have a more user-friendly format. The PMA for the F-16 will weigh less, will have a different keypad, and will be menu-driven to a greater extent. Because we were able to view only F/A-18 components and partially discuss F-16 components during the visits, the information necessary to form hypotheses about specific IMIS effects on F-16 training was somewhat limited. For example, when developing hypotheses about the IMIS capabilities to present remedial training, it is necessary to know whether the F-16 version of the PMA will allow an expert to receive novice level help (and vice versa), as needed, at any point in the lesson. Currently with the F/A-18, the technician must return to the beginning of the task rather than receive remedial assistance in the middle of a work order. This implies that if the technician is in the *expert mode* and wants to receive novice level help at the task level, he or she would have to get out of the task, go back to the beginning, and start over at a novice level, repeating much already-mastered task information.

Observation of Maintenance and Maintenance Training Process

Data on both the maintenance and the maintenance training processes were obtained by structured interviews at the Kelly AFB, Texas, Hill AFB, Utah, and Lowry AFB, Colorado. Therefore, the methodologies for obtaining these data are explained together. Below, we describe our methods for selecting Air Force Specialties (AFSs) and tasks, developing the questionnaire, and performing the situation analysis.

Selecting the Air Force Specialties

While IMIS is aimed at the entire spectrum of maintenance, only a small segment of the maintenance community was included in the IMIS Prototype Field Test scheduled for spring of 1993. The five F-16 sub-systems mentioned earlier were recommended for use by the Air Force Armstrong Laboratory in the Prototype Field Test, because they gave the broadest aircraft maintenance coverage. These were also considered to be the systems where IMIS potentially would have the greatest effect on both classroom and on-the-job training. In line with this, we reviewed all AFSs involved in aircraft maintenance as potential candidates for further research. A list was generated of eight AFSs that are involved in the maintenance of the above mentioned subsystems. Using the following criteria, three AFSs were chosen as candidates for further research.

Subsystem Coverage. The strongest candidate AFSs were those whose tasks address the largest majority of the five F-16 subsystems. In other words, it was necessary to identify the smallest number of AFSs containing tasks to cover maintenance of all five subsystems. Analysts found that there was not a one-to-one AFS-subsystem match for all subsystems, nor was there a single AFS that supported or covered all five subsystems. Three AFSs resulted from this analysis; they were: *Air Force Specialty Code (AFSC) 452X2A, F-16 Avionic Systems*, (which covered three of the subsystems), *AFSCs 452X5, Tactical Electrical and Environmental Systems*, and 454X4/A, *Aircraft Pneudraulic Systems* (each of which covered the remaining two subsystems). Thus all five F-16 sub-systems selected for the IMIS test were covered by three AFSCs.

Recency. The strongest candidate AFSs were those with most recently dated Occupational Survey Report (OSR) and Specialty Training Standard (STS) data. Analysts chose these criteria realizing that OSR data could change within a 3- to 5-year time period. And even then the most recent OSR data could still be out of date depending upon recently occurring changes. For instance, it is possible for the conduct of maintenance for certain tasks to change due to changes in TOs and this information not be included in the last occupational survey data collection procedures. In order to have the most accurate, relevant information for later decisions and research, the most recent data were needed.

Table 1
Maintenance Tasks Used in Training Situation Analysis

AFSC	TASKS
452X2/A: Avionic Systems	1. Isolate malfunctions to inertial navigation line-replaceable units. 2. Perform fire control radar integration checks. 3. Isolate malfunctions to head-up display pilot units.
452X5: Tactical Electrical & Environmental Systems	1. Perform leakage checks of cabin or cargo pressurization systems. 2. Perform operational checks of cabin or cargo pressurization systems. 3. Isolate malfunctions to cabin or cargo pressurization systems.
454X4/A: Aircraft Pneudraulic Systems	1. Perform operational checks of hydraulic power systems / Isolate malfunctions within hydraulic systems using hydraulic schematics. 2. Inspect aircraft installed hydraulic power systems. 3. Remove or install components of hydraulic power systems.

Selecting the Tasks

Specific task information for the selected AFSs was extracted from the OSR data along with accompanying Training Emphasis (TE) and Task Difficulty (TD) ratings. Tasks were chosen that met or exceeded the OSR-reported "high" rating for both TE and TD, and had high scores on *percent members performing* and *relative time spent on task ratings*. The assumption here was that tasks selected for IMIS demonstration, analysis, and hypothesis testing should be sufficiently rigorous in that they require (1) a large amount of training, (2) lengthy time to learn to perform, and (3) performance by the largest number of technicians. The individual tasks were then rank-ordered according to highest combined TE, TD and *percent members performing* ratings.

STS data for the relevant AFSs was reviewed in order to verify whether changes had taken place in the training of the selected tasks. These data were also reviewed to verify whether the tasks themselves were still relevant. The final selection of tasks to be used as the basis for the Training Situation Analysis was made by maintenance experts at Hill AFB, in each of the three

AFSs. These experts were asked to choose three tasks and rank order them according to those that were most frequently performed, and those for which personnel would have the most information to offer. Respondents referred to these tasks, which are listed in Table 1, when answering the questionnaire.

Developing the Questionnaire

To better estimate the impact IMIS would have on the training of various tasks, we developed an interview questionnaire to assess the current training situation in various environments (OJT, FTD, and Technical School). Information obtained from OSR and STS data, and from a literature review on maintenance and troubleshooting processes, was used to develop the questionnaire. Along with this, a decision criteria checklist for training/job aiding tradeoffs was developed from which statements were extracted for use in the questionnaire. These decision criteria were developed according to information obtained from research conducted on training/job aiding tradeoff decisions (Harless, 1979; Smillie, 1985; Zenyuh, Frey, Rouse & Lamb, 1991). It was hoped that responses to these statements would enable the analysts to determine whether use of IMIS for particular tasks was more appropriate as a job aid or as a training device. These results will be discussed in a later section (Findings Concerning Task Characteristics).

The interview questionnaire varied in length and content according to the job category of the personnel being interviewed. The questionnaire elicited information on namely task performance status, task characteristics as they relate to flightline maintenance, training issues, and troubleshooting. Different versions of the questionnaire were developed in order to obtain the most appropriate types of information from all personnel involved. For instance, questions posed to maintenance technicians were performance oriented, while the maintenance training manager received questions placing greater emphasis on maintenance training. Specific tasks (see Table 1) were included at the beginning of each questionnaire. Respondents were asked to refer to these tasks while answering all questions. The same questions were repeated for each task to determine variation across tasks. A supplemental set of questions pertaining to troubleshooting performance and training was also included. These questions did not address a specific task and were answered only once by each respondent. One questionnaire is presented in Appendix A.

Assessing the Maintenance and Training Situation

Interviews were conducted with maintenance supervisors, maintenance technicians, maintenance training managers, and FTD Instructors within operational units at Kelly AFB, TX and Hill AFB, UT. An informal briefing was first held at the 149th Tactical Fighter Group, Texas Air National Guard unit at Kelly AFB concerning the use of IMIS for maintenance and maintenance training activities. Structured interviews were then conducted with relevant personnel in order to pilot test the questionnaire. Based on feedback from the pilot testing, minor changes were made in the questionnaires before using them for the interviews at Hill AFB.

Additionally, interviews were conducted with technical school instructors, a course director, and a training developer at the Technical Training Center at Lowry AFB, CO. It should be noted

that training for only one of the three AFSs chosen for this project--*Avionics/452X2*--occurs at this installation. However, this particular AFS provides coverage for three of the five F-16 subsystems of interest as noted earlier. It was not feasible to interview technical school personnel for the two remaining AFSs.

Identification of the best qualified persons to be interviewed was accomplished using expert (nonprobability) sampling procedures. An Air Force point of contact was established at each base/Technical Training Center to arrange interviews. We specified criteria for selecting interviewees as shown in Appendix B.

Each respondent filled out the questionnaire during a structured-interview session with an individual analyst. This allowed the respondents to easily ask questions about the questionnaire and verbally elaborate on their answers.

III. TRAINING SITUATION ANALYSIS FINDINGS

3.1. Findings from the Literature Review

The literature review focused on two research topics, the maintenance process and the maintenance training process. The findings from the literature review were used in generating some of the questions for the structured interviews, and also in interpreting the data. A few of the important points from the literature review are summarized here.

3.1.1. Knowledge Used In Maintenance and Troubleshooting.

Research by cognitive psychologists has shown that people who are expert at a particular task possess a variety of different kinds of task related knowledge, from domain-specific procedures to general problem-solving strategies. Much of this knowledge is tacit, i.e., not easily available for conscious discussion by the expert. An effective way to train students on a task is to map out the repertoire of knowledge used by the expert and explicitly teach this to students (Gott, 1988). Recently, a number of psychologists have studied the complex process of maintenance and troubleshooting, and have identified some of the key knowledge used in these difficult tasks (Gott, 1988; Gugerty, 1989; Lesgold & Lajoie, 1991; Rasmussen, 1981). This knowledge is described below. Understanding it will help in determining how IMIS could be used affectively in maintenance training.

Most maintenance tasks, like tasks at other jobs, involve following pre-learned procedures. For example, a maintenance technician must follow safety and administrative procedures, as well as procedures for using tools and test equipment and for removing and replacing components. An experienced technician can perform these procedures easily. In contrast to procedure-following tasks are troubleshooting tasks, in which the maintenance technician must find and fix the cause of a malfunction in a system (e.g., an aircraft). Troubleshooting tasks can be very difficult, sometimes challenging the most experienced technicians to do complex problem solving. Errors in troubleshooting contribute significantly towards the 25% to 30% of the

military budget spent on maintenance (Means & Gott, 1988). Because of the difficulty and importance of troubleshooting tasks, we focused on these tasks in our literature review.

Table 2 lists the key knowledge required for expert troubleshooting under two categories, declarative (or factual) knowledge and procedural (or skill) knowledge. The procedural knowledge (or cognitive processes) is hierarchical in nature, with the coordination processes being the most general. These processes organize the use of strategies, which in turn control the use of the more specific procedures. There is no hierarchical relationship between the two types of declarative knowledge, mental-model and symptom-fault-association knowledge. Rather, each of these types of knowledge is used by different troubleshooting strategies, as is described below.

Mental model knowledge, in the context of troubleshooting, is knowledge of how the device or system works. It includes knowledge of the internal structure (or topography) of the system, the functions of system components, and the states (or behavior) of the system. A mental model can be used to answer what-if questions about the system, such as how the failure of a particular component will affect the behavior of the rest of the system. Symptom-fault associations are remembered associations between specific symptoms (improper system behaviors) and the internal system faults that usually cause them. When your mechanic diagnoses your car problem instantly after listening to the engine and looking at the color of the exhaust smoke, he or she is using symptom-fault associations.

Table 2
Knowledge Used in Maintenance and Troubleshooting

Knowledge Category	**Knowledge Type**	**Description**
Declarative	Mental Models	"How-it-works" knowledge pertaining to system structure (topography), function, and behavior.
	Symptom-fault Associations	Associations between symptoms and faults. Fault probabilities.
Procedural (Cognitive Processes)	Procedures	Step-by-step information about how to perform specific actions
	Strategies	More general processes that coordinate the use of procedures, using mental models or symptom-fault associations.
	Coordination Processes	Very general, metacognitive processes that involve activities such as strategy selection.

Procedural knowledge consists of step-by-step information about how to perform specific actions, such as testing resistance with a multimeter. Strategies are more general processes that help organize technicians' search for the faulty component. There are two main kinds of troubleshooting strategies (Rasmussen, 1981). The first involves using symptom-fault-association knowledge to recall the fault that was found to cause a symptom in the past, and then testing for this fault. The second involves using mental-model knowledge. An example of the second type of strategy is elimination, in which the technician uses information about correct system behaviors and knowledge of system function and topography to eliminate from consideration components that can be inferred to be working. So, if your car will not start but your lights work, you can eliminate the battery as a possible cause of the problem.

Coordination processes involve metacognitive thinking, in which technicians monitor how well their strategies are meeting the various constraints of the problem (e.g., finding the fault, having a plane ready on time) and change strategies accordingly. A technician is using coordination processes when he or she decides, because of time constraints, to stop trying to isolate (locate) a specific fault and instead make a costly component replacement that will fix the problem quickly.

3.1.2. Maintenance Training Processes

Two ideas are presented in this section, the first concerning the content of training and the second the method. Regarding content, the various types of knowledge presented in Table 2 are the results of research studies and cognitive task analyses, which involve formal and informal observation of experts' problems-solving performance. The goal of these studies and analyses is to reveal the explicit and implicit (tacit) aspects of experts' problem-solving knowledge. A number of educational researchers have suggested that an effective program for teaching a complex cognitive skill like troubleshooting should *explicitly* teach all the types of knowledge necessary for expert task performance. (Collins, Brown & Newman, 1989; Gott, 1988). Some of the key types of troubleshooting knowledge in Table 2, such as strategies and metacognitive (coordination) knowledge, often are not taught explicitly in maintenance training (Means & Gott, 1988). Strategic and metacognitive knowledge is not included explicitly in TOs, so technicians will not pick it up on the job from using TOs.

Regarding methods of training, a number of researchers have suggested that problem-based learning is very effective in teaching complex skills like troubleshooting and maintenance (Collins et al., 1989; Gott, 1988). That is, students need to practice solving problems similar to those they will solve on the job. This focus on realistic problem-solving is used in Air Force OJT. Since OJT is a major emphasis of this paper, we will focus on a training method called cognitive apprenticeship training (Collins et al., 1989). This method fits well with the specific training techniques used in Air Force OJT, including problem-based learning. However, apprenticeship-training techniques can also be used in the classroom, so this approach will help in understanding instruction in the Technical School and FTD classrooms. In addition, a key potential use of IMIS in training is as a simulator, where students can practice solving realistic

maintenance problems (Babiarz et al., 1989; Link et al., 1987). Thus, the apprenticeship-training approach is useful in understanding how IMIS can be used in training.

As mentioned above, apprenticeship training is problem-based. Whether it takes place in a classroom or on the job, much of the learning takes place while students solve problems similar to those they will face in the workplace. The techniques of apprenticeship training include: *explicit modeling* by the teacher of the skills needed for expert performance; *coaching*, in which the teacher supports the students via hints or reminders during problem-solving; and *fading* in which the teacher gradually withdraws support as the student progress. These techniques focus on the cognitive aspects of learning. In addition, apprenticeship training also emphasizes the social context of learning. For example, *collaboration* and learning in multiple contexts is encouraged. Apprenticeship training has been found to be effective in teaching complex cognitive skills, including troubleshooting (Collins et al., 1989; Lajoie & Lesgold, 1989).

3.2 Findings from Observations of IMIS

One of the main purposes of IMIS is to integrate the wide range of information needed to perform maintenance activities and give technicians easy access to this information through a single system. IMIS is intended to integrate the following kinds of information:

- Technical orders
- Diagnostic information
- Flight data
- Aircraft historical data
- Supply and management data
- Training data

Currently, only the technical orders and diagnostic information are available in the IMIS prototype.

Figure 1 shows the relationships among the current IMIS hardware components. In its present configuration, the IMIS hardware consists of the Maintenance Workstation, the Portable Maintenance Aid (PMA), and the Aircraft Interface Panel. The workstation is used during the early stages of maintenance to help debrief the pilot, analyze flight and historical data, schedule the maintenance activity, and assemble a set of TOs and other information that can assist the technician during troubleshooting and repair. A portion of this information is downloaded into a memory module which is inserted into the PMA. The PMA is a rugged computer about the size of a commercial laptop. The technician takes the PMA to the flightline and hooks it up to the plane with the Aircraft Interface Panel. During troubleshooting and repair, the technician has access, via the PMA, to any TOs that are needed and to additional advice from IMIS's Diagnostic Module. The PMA can also access information from the aircraft, such as built-in-test data. The technician can use the PMA to order parts and to issue maintenance status reports via a radio link to the workstation.

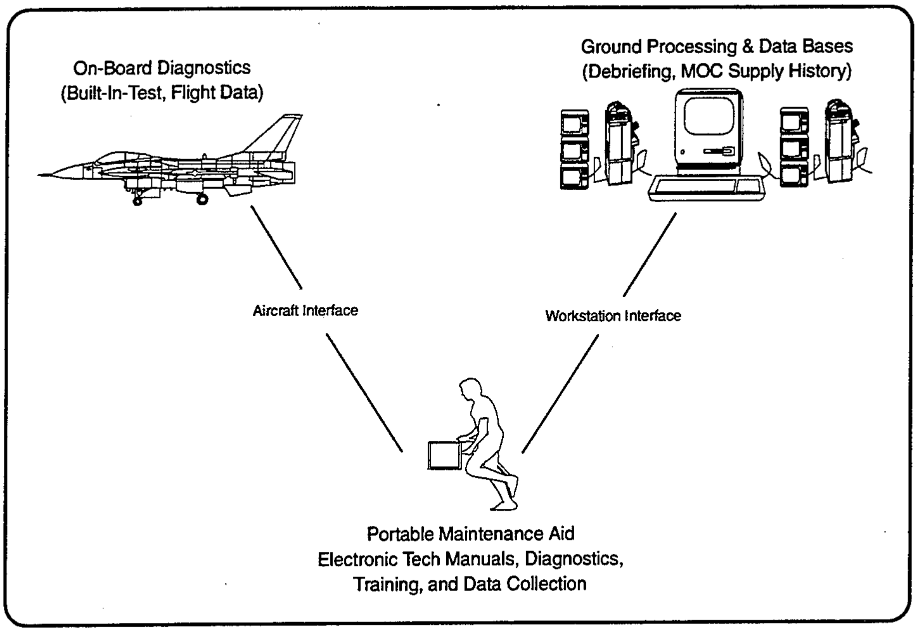

Figure 1. Relationships Among IMIS Hardware Components

One of the main components of IMIS that can be used in training is the Diagnostic Module (DM) (Cooke et al., 1991). This software module provides expert troubleshooting advice to the technician. The DM uses data from an IMIS database called the CDM (Earl et al., 1990). The CDM contains two types of information. The first is information from TOs. TOs are explicit, step-by-step procedures for performing troubleshooting and repair activities. A major advantage of IMIS over the current system of paper TOs is that IMIS saves technicians the trouble of carrying thousands of pages of manuals to the flightline and searching back and forth from one manual to another during troubleshooting. However, IMIS provides more diagnostic aid than just on-line TOs. The second type of information in the CDM is data on common aircraft symptoms, the faults that could cause specific symptoms, fault probabilities (i.e., component failure rates), and the expected results of tests and replacements.[1] These data are used by the DM to provide advice during troubleshooting beyond that contained in the TOs.

At the start of a troubleshooting problem, a description of the symptoms exhibited by the aircraft is input into the PMA. The DM then creates a recommended list of tests and component replacements that could help isolate (or locate) the faulty component. This list is rank ordered, with the most effective troubleshooting action shown first. The technician is free, however, to perform any troubleshooting action he or she wants, including actions not on the recommended list. After a test or replacement is completed, the information from this action is input into the PMA and the DM calculates a new list of troubleshooting actions. This process is repeated until, in most cases, the technician isolates the fault. Then the PMA will show the technician the appropriate TO to help him or her repair the fault.

[1] A symptom is the outward manifestation of a problem with the aircraft. A fault (e.g., a broken component) is the underlying cause of a symptom.

The DM considers a wide variety of information in order to choose recommended tests and replacements, including the faults commonly associated with the current symptoms, the failure rates of potentially faulty components, the time to perform tests and replacements, and the availability of replacement parts. In order to assess IMIS's potential as a training system, it is helpful to compare the knowledge and processes used by the DM with those used by human experts during troubleshooting. As shown in Table 2, human troubleshooters use mental-models, symptom-fault-associations, procedures, strategies, and coordination processes.

The DM uses extensive symptom-fault-association and procedures knowledge. The data in the CDM on symptoms, faults, failure probabilities, and test and replacement results are equivalent to symptom-fault associations. The CDM data on TOs are examples of procedures knowledge.

In addition, the DM uses two troubleshooting strategies that are commonly used by expert technicians. The first of these is elimination. Recall that in this strategy, all components that are spanned by (i.e., lead into) a troubleshooting test yielding a successful result (a pass) are eliminated from the set of potentially faulty components. Figure 2 shows a screen from an early version of IMIS during troubleshooting of a fault in the F-16 Stores Management System. The recommended test (31AH2) is listed in the upper right corner, along with other test options. The components outlined in gray are the set of potentially faulty components diagnosed by IMIS, given the current information. The components shaded in black are those that will be eliminated if the recommended test passes. If the technician performs this test and it passes, then, on the next IMIS screen, these components will not be outlined in gray.

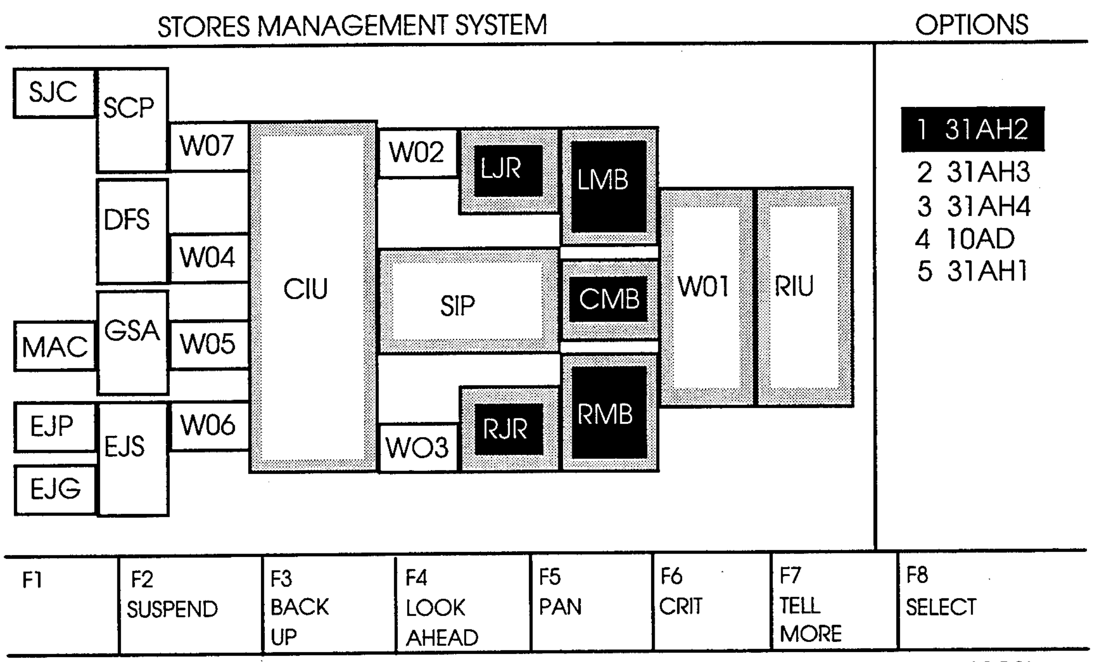

Figure 2. IMIS (PMA) Display During Troubleshooting (from Babiarz, et al., 1989)

The DM also uses a version of half split (or binary search), a strategy that is used by human experts. A typical use of half split by a person employs topographic mental-model knowledge. For example, if the person knows that the current set of potentially faulty components is connected in a chain, then the half-split strategy would involve testing a component in the middle of the chain. This would ensure that, whether the test passes or fails, half of the components can be eliminated. Note that the test recommended by the DM in Figure 2 would reduce the set of potentially faulty components in half, reflecting the half-split strategy. However, the tests recommended by the DM do not always conform to the strict half-split strategy, because the DM considers other information in addition to the half-split strategy when choosing tests, information such as component failure rates and the time to perform tests and replacements.

In terms of coordination processes, the DM considers some of the same kinds of information that a person would in planning how to attack a troubleshooting problem and deciding what strategies to use. This includes information such as the time to perform tests and replacements, and parts availability. However, the DM's overall coordination processes are much different than humans. The DM algorithm uses an exhaustive-search approach, evaluating every fault (in its database) that could possibly cause the current symptoms, and every test that could possibly give information about the most likely fault. These faults and tests are evaluated via extensive numerical computations that are not used by human troubleshooters.

Another key difference between the DM and human troubleshooters is that the DM uses very little mental-model knowledge, that is, very little knowledge of the system functions and topography, in its reasoning. One kind of mental-model knowledge that *is* used by the DM is knowledge of the components spanned by different troubleshooting tests. This knowledge is used by the elimination and half-split strategies. Other than this, the DM relies primarily on symptom-fault association knowledge, rather than mental-model knowledge. This emphasis is reflected in the block system diagram in Figure 2. This diagram is based on "fault connectivity rather than functional connectivity" (Cooke et al., 1991, p. 42). A diagram showing functional and topographic connectivity (e.g., a schematic) would contain mental-model information.

These similarities and differences between the human and the DM's approach to troubleshooting will affect how IMIS can be used as an *intelligent* training system. For example, a key feature of an intelligent training system is its ability to explain its reasoning processes to students. A system's explanation capabilities will be more effective to the extent that its reasoning processes approximate those of a human expert (Anderson, 1988). The above analysis shows that, although the DM was not intended to simulate human troubleshooting processes, its knowledge and reasoning processes overlap considerably with those used by expert troubleshooters. In Anderson's (1988) terms, the DM is somewhere between a *black-box* expert that reasons completely unlike humans and a *glass-box* expert that accurately mimics human reasoning. In its current capacity as a job aid, the DM can explain its recommended tests and replacements using the following information from the CDM: the expected results of tests and replacements (symptom-fault association knowledge) and the time for tests and replacements.
It would be easy for the DM to construct explanations based on other symptom-fault-association knowledge and troubleshooting strategies, and more difficult (though not impossible) to

construct human-like explanations in term of mental-model knowledge and coordination processes.

Research by Kieras (1992) suggests that in order to reason effectively about malfunctioning systems, technicians need mental-model information about the topographic structure of the system. However, the fact that the DM does not use much mental-model knowledge is not a major shortcoming in terms of its use as an instructional system. Very few computer-based systems can reason flexibly about a system using mental-model knowledge. Those that can, such as the RAPIDS system (Towne & Munro, 1991), have not been implemented for systems as complex as the F-16. In addition, no existing computer-based systems use all of the knowledge that an expert troubleshooter does. Ways of compensating for the DM's de-emphasis of mental-model knowledge will be discussed in a later section.

Another key feature of an intelligent training system is its ability to construct a model of an individual student's knowledge and reasoning (VanLehn, 1988). A student model may be important if IMIS is to be used as part of an intelligent tutoring system (ITS) that tracks students' knowledge and performance and adjusts its instruction to students' current knowledge state. IMIS's lack of human-like mental-model and coordination knowledge may hamper its ability to create an effective student model. However, some researchers have argued that useful ITSs can be developed without detailed student modeling (Newman, 1989). How IMIS's capabilities will fit into an intelligent training system will be discussed further in a later report.

Our final comment concerning IMIS's capabilities focuses on the accuracy and usefulness of its troubleshooting advice. Since IMIS uses troubleshooting knowledge and strategies beyond that in the TOs, one would expect that IMIS would provide more accurate troubleshooting advice and would help technicians solve some troubleshooting problems that could not be solved using only the TOs. However, the evaluations of IMIS conducted so far have not provided convincing evidence that IMIS is more accurate that the TOs. For example, an evaluation conducted in the summer of 1992 at the Marine Corps Air Station, Beaufort, SC compared the performance of technicians using IMIS and TOs. Troubleshooting accuracy was measured by variables such as the number of failures to find a fault and the number of unnecessary line-replaceable-unit (LRU) removals. However, there were so few cases of failure to find a fault or unnecessary LRU removal that the question of whether IMIS outperformed the TOs on these variables could not be answered (E. Carlson, personal communication, November 15, 1992). The question of whether IMIS is more accurate than the TOs is important in evaluating IMIS's potential effectiveness as a training system, as will be discussed further later in this report.

3.3 Findings Concerning Other Automated Systems

In this section we describe the characteristics of other automated Air Force systems that might have an impact on, or enhance, those capabilities of IMIS which would be used to support Air Force maintenance training. Later in this report we will develop hypotheses about how IMIS might interact with these systems.

3.3.1 Base Training System (BTS)

This system is expected to exist at all operational bases in support of the OJT environment. Currently it consists of three training management components each of which is described below.

Training Requirements Management. This component provides the following:

- Identification of all pertinent performance and training requirements that are managed at Air Force job sites;
- Identification of references for performance and training requirements;
- Prioritization of performance and training requirements;
- Assessment of personnel qualifications to determine suitability for assignment to specified duty positions; and
- Development of behavioral objectives.

Training Progress Management. This component provides the capability to perform the following functions:

- Generate and maintain on-line training records;
- Schedule training and evaluation events; and
- Generate standard and ad-hoc training effectiveness reports.

Resource Inventories Management. This component provides the capability to identify and maintain an inventory (list) of resources required for performance, training, and evaluation of specialty tasks. Specified are resources required for each task, subtask, behavioral objective, and event within a specialty. (Vigue & Young, 1991, p. 5)

3.3.2 Advanced Training System (ATS)

This system will exist at the five Technical Training Centers for the purpose of design, development, delivery, evaluation, and course management for various training activities. It will include some of the following capabilities:

- Design tools for lesson plans, sequences, flow charts, and storyboards;
- Automate course control documentation with cross-referencing to requirements and resources;
- Provide student remediation and practice;
- Monitor student performance and status monitoring;
- Review training data;
- Provide on-line coordination, review, and editing of training documents; and
- Schedule students, instructors, equipment, and facilities.

Currently this system will communicate with the Occupational Measurement Squadron system (for task analysis data), the Extension Course Institute (for Career Development Course materials), and the Air Force Training Management System (for class schedule and student accounting information).

3.3.3 Automated Instructional Design Advisor (AIDA)

This system was designed to be an automated and integrated collection of tools to assist in the design, development, and delivery of instruction. Its goal is to provide intelligent and automated assistance throughout all phases of instructional development, particularly computer-based instructional development, for general maintenance training. Thus, AIDA contains instructional expertise which allows a subject-matter expert to directly author instruction without needing the advice or assistance of an expert instructional designer.

3.3.4 Core Automated Maintenance System (CAMS)

This system exists in active duty and reserve units for the purpose of automating and integrating data concerning maintenance activities. Data can be recorded and stored for such maintenance functions as status and inventory, operational events, automated test equipment reporting system, equipment transfer procedures, personnel transfer procedures, and training management, to name a few. It also interfaces with the Standard Base Supply System (SBSS).

The training management portion of this system allows personnel to record and maintain data on ancillary training and OJT. At the reserve units training status information for personnel can be recorded and viewed at the course level, at the work center level, or at the individual level. For instance, a typical printout for an individual would list all relevant courses of instruction for his or her specialty with the status for each course being given as *completed, overdue,* or *due for annual update*. In the active duty units status information at the task level would be given as well for individuals and for work centers.

In order to log-on to the system, personnel (from technicians to supervisors to trainers) must have an i.d. number and password. Personnel with this information may record relevant data (such as aircraft repair information) or view relevant information (such as personnel status for a workcenter). The computer recognizes each identify number (ID) and, based on pre-determined access information for various personnel, allows an individual to view only documentation that would be relevant to his or her duties. Certain documentation must be requested through the CAMS operations personnel.

3.4 Findings Concerning the Maintenance Process

In this section we describe the F-16 maintenance process. Although the main focus of this report is the maintenance training process, coverage of the maintenance process itself is necessary for the following reasons. As mentioned before, one must understand the nature of a task before designing training for that task. Since, in a later phase of this project, we will develop a computer-based demonstration of how IMIS can be used in F-16 maintenance training, we need to first understand the maintenance process. An understanding of this process leads to a number of specific recommendations for how IMIS can be used in training. These are described later in the report.

Table 3
Demographic Information for Kelly AFB Maintenance Supervisors (N=5)

Extent of Experience (answered in number of years)	Mean	Standard Deviation
How long in... Air Force/Air National Guard	22.2	11.1
Maintenance Career Field	19.4	7.8
Current Specialty	19.4	7.8
Current Work Center	13	8.8
Maintenance Supervisor	14	1
OJT Trainer	14.3	8.2

Questionnaire data for 25 Air Force personnel and 5 Air National Guard (ANG) personnel, and observational data, were used for this analysis. Demographic information for these personnel is shown in Tables 3, 4, 5, and 6. These tables are broken down by base (Kelly AFB, Hill AFB and Lowry AFB) and, when necessary, by category of personnel. Demographic information applies to this section as well as the following section on the training process.

Table 4
Demographic Information for Lowry AFB Technical School Instructors and Course Developer for Avionics (452X2)* (N=5)

Extent of Experience (answered in number of years)	Mean	Standard Deviation
How long in... Air Force	10.7	5.4
Maintenance Career Field	10.45	5.01
Current Specialty	7.7	6.4
Tech School Instructor, Course Supervisor, etc.	3.6	1.5

*One instructor interviewed was a course supervisor as well. (The same questionnaire format was used for all five personnel)

Our sample size is relatively small due to various constraints in collecting data. However, we feel our results are a fair representation of what actually occurs in Air Force maintenance and maintenance training environments. This is not to say that our data necessarily reflect specific occurrences in these environments, rather a general representation. We base this confidence not only on the data, but on literature reviews of these environments and upon the advice of subject matter experts other than those interviewed.

Table 5
Demographic Information for Hill AFB Technicians (N=6)

Extent of Experience (answered in number of years)	**Avionics (N=2)**		**Environm. (N=1)**	**Pneudraulics (N=3)**	
	Mean	**Std. Dev.**		**Mean**	**Std. Dev.**
How long in... Air Force	7.5	6.4	1.5	12.7	4.9
Maintenance Career Field	7	7.1	1.5	12.7	4.9
Current Specialty	4.5	3.5	1.5	10.8	7.5
Current Work Center or Detachment	2	0	1.5	1.7	.29

3.4.1 The F-16 Maintenance Process

Aircraft maintenance activities fall into two categories: scheduled and unscheduled. Scheduled maintenance occurs when aircraft are temporarily taken out of service for the purpose of performing routine preventative maintenance. Activities include removing and installing components, aircraft overhauls, and operational checkouts (which involve checking whether a subsystem is working correctly).

Unscheduled maintenance occurs as a result of aircraft malfunctions requiring immediate repair. It consists of the troubleshooting and repair work necessary to get malfunctioning aircraft back in service. This usually involves three processes: fault detection, fault isolation (locating the cause of a problem), and fault recovery (repair). We use troubleshooting as a general term encompassing all three of these processes. Two key factors affect the way in which F-16 unscheduled maintenance is performed in the Air Force. The first of these is system complexity. Like any modern jet aircraft, the F-16 is a very complex system, with subsystems for propulsion, avionics, environmental control, communications, and other functions. A large array of equipment is tightly fit into a relatively small fuselage. Often, in order to test or replace a component, a technician must remove other components that block access to it.

The second factor affecting F-16 unscheduled maintenance has to do with the time limitations for performing the maintenance. On the flightline, where much of the unscheduled maintenance occurs, planes must often be "turned" -- that is, repaired and readied for flight -- in a matter of a few hours (in combat, even less).

Table 6

Demographic Information for Supervisors and FTD Instructors in each AFSC (N=14) and the Maintenance Training Manager (N=1) at Hill AFB

Experience Level Questions (answered in number of years)	Avionics (452X2/A)			Environmental (452X5)			Pneudraulics (454X4/A)				Maintenance Training Manager (N=1)
	Supervisors (N=4)		FTD Instructors (N=1)	Supervisors (N=3)		FTD Instructors (N=1)	Supervisor (N=3)		FTD/LST Instructors (N=2)		
	Mean	Standard Deviation		Mean	Standard Deviation		Mean	Standard Deviation	Mean	Standard Deviation	
How long in... Air Force	13.5	2.7	9.5	13.7	3.1	13	13.3	2.5	15.5	.7	18
Maintenance Career Field	13.5	2.7	9.5	12.7	3.8	13	11.3	4.5	15.5	.7	18
Current Specialty	7.4	4.8	9.5	12.7	3.8	2	11.3	4.5	15.5	.7	18
Current Work Center or Detachment	1.7	1.9	3	3.8	4.6	2	1.03	.96	1.8	1.7	N/A
Supervisory Position	7.5	4.1	N/A	7	3	N/A	6.3	1.2	N/A	N/A	N/A
OJT Trainer/FTD Instructor Position/Training Manager	11	3.83	3	9.3	6.8	2	10.7	2.1	4.3	5.2	18

The twin factors of systems complexity and time constraints have led the Air Force to develop a system of LRUs and standardized troubleshooting and repair procedures (TOs) in order to simplify and speed up maintenance procedures. An LRU is a component or set of components that can be removed from the aircraft as a unit and sent to a repair shop for further troubleshooting and possibly repair. Using LRUs cuts down the amount of troubleshooting maintenance technicians have to do on the flightline. TOs provide a set of procedures that frequently allow a maintenance technician to find the faulty LRU without time consuming problem solving.

3.4.2 The Maintenance Process at Hill Air Force Base

Two groups of people are involved in maintenance activities at Hill. The first group consists of the maintenance technicians and supervisors who perform the initial fault isolation and recovery on the flightline. Some of the main resources used by maintenance technicians are TOs, which include job guides (detailed procedures for operational checkouts and for removing and replacing components) and fault isolation charts (decision trees to aid in fault isolation).

In performing their jobs, maintenance technicians often isolate a fault to an LRU and then remove and replace the LRU. The faulty LRU is then sent to the "back shop." There, a second group of technicians use automatic test equipment to diagnose the fault within the LRU and repair it, if possible.

As mentioned above, the maintenance process (at least for unscheduled maintenance) consists of fault detection, fault isolation and fault recovery. Sometimes fault detection occurs when pilots notice problems in a plane's operation during flight. Other times, faults are detected by maintenance technicians or on-board computers during pre- or post-flight operational checkouts. The on-board computers that test for faults are called built-in-test equipment.

The first step in fault isolation is to describe the problem (i.e., the symptoms). A maintenance technician initially receives a work order containing a brief description of the problem, which is obtained from a pilot debriefing. Technicians may question the pilot further about the specifics of when and how the problem occurred. The second step is to isolate the fault using a fault-isolation (FI) chart and other TOs. The FI chart provides a decision tree telling the technician what tests and component replacements to make and how to interpret the results of these tests and replacements. To perform a component replacement required by an FI chart, a technician often needs to use a job-guide TO.

The need to switch among several TOs while performing a single task causes a number of problems. First, the TOs are bulky and technicians often have to carry several TO manuals comprising thousands of pages. Second, and more importantly, information in TOs is at times hard to locate and technicians can sometimes get lost while using them. For example, Tenney and Kurland (1988) report a case of an expert radar technician turning to the wrong procedure in a manual and having a hard time recovering from this error. Another significant problem with FI-chart TOs is that they fail to isolate some faults. A final problem complicating troubleshooting is that, although efforts are made to update TOs regularly to correspond to aircraft changes, sometimes the TOs are not quite up to date. When a technician gets lost in following a TO, or the TO does not isolate a fault, he or she must use problem-solving skills to

recover from this situation. These skills include using some of the kinds of troubleshooting knowledge described above, such as mental-model knowledge and troubleshooting strategies.

We collected data on the extent to which maintenance technicians have to go beyond the TOs in flightline troubleshooting. One question asked supervisors and maintenance technicians to estimate the percentage of technical-order faults and problem-solving faults encountered by technicians. Problem-solving faults were defined as those where "the technical orders do not provide enough information to diagnose or repair the fault. Here the technician must make major decisions about what tests or repairs to make and/or how to sequence these tests and repairs." All other faults were defined as technical-order faults. The mean percentage of problem-solving faults estimated by the 20 technicians and supervisors interviewed was 30% (median = 22.5%). Thus, technicians must use information and knowledge beyond that in the TOs for 30% of the problems they face.

What troubleshooting methods do technicians use when they must go beyond the TO? We listed five methods of troubleshooting and asked technicians and supervisors to estimate the percentage of troubleshooting tasks on which the average technician would use each method. The methods and mean percentage estimates are shown in Table 7. These data suggest that technicians often use methods other than following TOs, including some methods that involve problem-solving skills, such as using analogies and troubleshooting strategies.

Table 7
Troubleshooting Methods Used

Method	**Mean Percentage of use**
Follow technical orders	64%
Recall how he/she solved the same problem before and use this procedure	56%
Recall how he/she solved a similar problem before and use this as an analogy or example	51%
Ask co-workers for help	36%
Use troubleshooting strategies (such as working backwards from the symptom, eliminating components known to be working, and half split)	46%

3.4.3 Summary of the Maintenance Process

The complexity of the F-16 and the time pressures inherent in flightline maintenance led the Air Force to institute a standardized maintenance system based on TOs and LRUs. Most of the time, this system achieves its goal of simplifying and speeding up the maintenance process. However, it is not always successful. Sometimes, technicians get lost or misinterpret the TO, or the TO cannot isolate a fault. Our data show that for about 30% of unscheduled maintenance problems, technicians must go beyond the TOs and use other approaches such as troubleshooting strategies and analogies to similar problems. This 30% figure is of practical significance, especially since the difficult problems that require more than TO knowledge probably take up much more than 30% of unscheduled maintenance time.

The pilot data we collected at Kelly AFB shows a pattern similar to the Hill AFB data. Four maintenance supervisors at Kelly estimated that, on average, technicians must go beyond the TOs on 47% of unscheduled maintenance problems, and that technicians use troubleshooting methods other than TOs (i.e., the methods in Table 7) from 20 to 40% of the time.

A number of maintenance personnel at Hill and Kelly AFBs described a problem with the current reliance on TOs and LRUs. The TO/LRU system has led to a two-tiered system of maintenance technicians, less experienced LRU swappers who must rely on TOs, and expert technicians who can go beyond the TO procedures to diagnose and repair the more difficult problems. Our earlier analysis of the knowledge required for expert troubleshooting (see Table 2) suggests that the less experienced technicians primarily are using procedures knowledge, while the experts are using a wide range of troubleshooting knowledge, including procedures, strategies, coordination processes, mental models, and symptom-fault associations.

In our description of the maintenance process at Hill AFB, we have emphasized troubleshooting tasks, and, in particular, the problem-solving aspects of troubleshooting. We chose this emphasis because of the difficulty and importance of these tasks (as discussed here and in the literature review section). However, we wish to re-iterate that maintenance activity also includes many non-troubleshooting tasks. Many of these tasks involve following pre-learned procedures (e.g., safety and administrative procedures, and procedures for using tools and equipment). Also, as our data show, many troubleshooting tasks consist of following procedures.

3.4.4 Conclusions Concerning the Maintenance Process.

One advantage of the TO/LRU system is that it lessens the need for more extensive training of maintenance personnel. As long as a small group of expert technicians is available to handle the more difficult troubleshooting problems, the system works well with a large group of less experienced technicians which must rely primarily on TOs.

However, the current system is vulnerable to the loss of key maintenance personnel. It also is at odds with the goals of the Rivet Workforce program, which emphasizes training generalists. To be effective generalists, technicians need more than low-level knowledge of procedures. They need mental models, strategies, and metacognitive knowledge that will allow them to work effectively on a wide range of systems and aircraft.

This analysis suggests that the Air Force has a pressing need to train more maintenance personnel who can use the multiple kinds of knowledge required of expert troubleshooters. This need raises a key question for how IMIS is to be used in training. Can IMIS help teach technicians a broad repertoire of troubleshooting skills that will allow them to become problem solvers instead of LRU swappers? On the other hand, since many maintenance tasks involve simply following procedures, the question also arises as to whether IMIS can train these procedures. Our preliminary answers to these questions will be given later in this report.

3.4.5 Findings Concerning Task Characteristics

The section following this one focuses on the Air Force maintenance training environment. Before discussing the training environment, we will first consider the question of which

maintenance tasks would be most amenable to training. To get at this question, one section of the questionnaire (the Task Characteristics section, in Appendix A) asked respondents to indicate *yes* or *no* to 33 questions regarding task performance. As with other questions, these responses were given for each of the reference tasks in Table 1. As mentioned earlier, these questions were generated from research on the topic of tradeoffs between training and job aiding. The answers to our questions would be used to determine whether emphasis should be put on training or job aiding for each reference task.

A key was developed whereby each yes or no response was transformed to a training or job aid tally, with a +1 tally indicating a response favoring training, and a -1 indicating a response favoring job aiding. Responses were totaled for each respondent and each task. These totals could theoretically range from -33 to +33. The sign of the total indicated the respondent's preference for training (positive) or a job aid (negative) for a particular task. The magnitude of the total indicated the degree of the respondent's preference for training or job aiding for the task.

Results revealed much variation in responses across personnel in a single AFS and for a single task. However, when comparing the various tasks within an AFS or between AFSs there was no strong indication of whether the performance of any of these tasks would benefit more from the use of a job aid than from training. The means for all tasks were close to 0, ranging from -2 to 3.

3.5 Findings Concerning the Maintenance Training Process

3.5.1 Air National Guard Maintenance Training

As mentioned earlier, the interviews at Kelly AFB were a pilot testing phase for the measurement instruments (questionnaires). The questionnaires were modified based on feedback from the interviewees. Revised versions were then used at Hill AFB and Lowry AFB. Interviews that were conducted included personnel who were highly skilled in their AFSC, and all five were supervisors. Less-experienced maintenance technicians were not available.

During this phase certain training issues were expressed. First, there is currently no training available to fill gaps between information contained in the TOs and problems encountered while actually troubleshooting. If a technician runs into a troubleshooting problem not covered in the TO, most often he or she has to either consult with expert technicians or attempt to solve the problem alone by using problem-solving skills and past experience. Second, training at the guard unit at Kelly AFB is strictly OJT. Most technicians there fall into three categories: 1) experts, who have extensive prior experience and Technical School training, 2) weekend journeymen maintaining their skills, and 3) novices with little or no prior experience who need extensive OJT. Third, because the guard unit is limited in the number of aircraft it maintains, training only takes place when there are breakdowns *and* there are enough personnel and time to train a technician in the skills that are needed. Meeting all these conditions is very difficult.

3.5.2 Air Force Maintenance Training

Air Force technical training is a standard and structured path for most maintenance specialties. After basic training, all Air Force recruits assigned as maintenance technicians go

through Technical School. Then, they are assigned to a base where they receive OJT as well as classroom instruction from a Field-Training Detachment (FTD) or Logistics Support Training (LST). We collected data on each of these training environments, and will describe our findings for each environment in turn, following the sequence in which trainees usually encounter them.

Technical School

Our data on Technical School training come from interviews conducted at Lowry AFB, which focuses on the Avionics maintenance specialty. Most trainees come to this environment having very limited or no knowledge of the skills needed for their future Air Force jobs. Therefore, pre-instructional assessment is not conducted, and instruction is pre-determined based on established course objectives. These objectives and corresponding blocks of instruction are based on what is required by the particular AFS (i.e., the types of skills and knowledge required to successfully maintain relevant aircraft) and developed into a complete course. Each course has course control documentation including a Plan of Instruction (POI), which details the steps that should be followed for proper instruction of all course objectives. The POI is divided into sections for each objective. Each section lists the pre-determined procedures to be followed and includes personalized notes from the instructors that provide more guidance for carrying out a particular lesson. Workbooks or study guides are normally available for students. These include information to be discussed in class, additional explanatory information, exercises, and quizzes for each unit of instruction.

Trainees initially receive eight or more weeks of instruction in general electronics theory. Following basic electronics training, information specific to Avionics is taught in a twelve week course. This course begins with two blocks of instruction on general maintenance procedures (one being an introduction to maintenance), followed by a block concerning the use of TOs, and then several blocks on more specific information for various subsystems.

In terms of content, the Avionics course focuses on teaching functional information rather than theory. We asked two questions to assess the content taught in this domain. The first question was relevant to a wide range of maintenance tasks (specifically, the reference tasks in Table 1). For each reference task, respondents were to indicate which of the content areas in Table 8 were taught.[2] As the table shows, Technical School instructors most frequently teach system/subsystem knowledge. Subtasks and a variety of procedures are taught less often.

[2] For Tables 8 through 11, percentages indicate the proportion of times an answer was chosen. Percentages were obtained by dividing the actual number of tallies for an answer by the possible number of times an answer could have been chosen by all personnel across all three tasks.

Table 8
Content Taught Concerning General Maintenance Activities

Content Area	Technical School	FTD	OJT
System/subsystem Knowledge	100%	91%	81%
Administrative Procedures	50%	32%	59%
Subtasks	50%	27%	91%
Equipment/Tool Familiarization	42%	82%	78%
Extenuating Flightline Procedures	33%	36%	55%
Other	50%	0	0

Our second question concerning course content was relevant to troubleshooting tasks in particular. It asked for instructors to estimate how much coverage they gave to the various kinds of troubleshooting knowledge presented in Table 2 (with 1 indicating no coverage, 3 moderate coverage, and 5 extensive coverage). The results from this question are shown in Table 9. These data suggest that Technical School instructors are aware of the various types of knowledge necessary for expert troubleshooting, and try to give all of these at least moderate coverage in their classes. The most extensive coverage was given to diagnosis and repair procedures and mental-model knowledge.

Table 9
Content Taught Concerning Troubleshooting (1 = no coverage, 3 = moderate coverage, 5 = extensive coverage)

Content Area	Technical School	FTD	OJT
Mental Model--Device	4.2	4.7	4.3
Mental Model--Topographic	3.8	5.0	3.3
Symptom-Fault Associations	2.8	4.3	3.4
Procedures for Diagnosis & Repair	4.2	3.7	4.1
Test Procedures	3.0	4.0	3.2
Troubleshooting Strategies	3.6	4.0	3.2
Coordination Processes	2.8	3.7	3.1

A variety of teaching methods are used in the Avionics course. As shown in Table 10, instructors report that the lecture approach (formal training) is used most often. The other methods, most of which correspond to the apprenticeship-training techniques of modeling (demonstration), coaching (assistance), and independent practice, are used less often in Technical School.

Table 10
Maintenance Training Methods

Type of Method	Technical School	FTD	OJT
Formal Training	100%	100%	52%
Demonstration and Practice	75%	95%	79%
Oversight and Assistance	25%	45%	78%
Independent Work With Checks	25%	27%	45%
Computer Based Training	0	5%	10%
Career Development Course	0	0	5%

One specific training method -- allowing students to practice maintenance activities on simulators or actual aircraft -- is of special importance because it allows training of the problem-solving aspects of maintenance. The Avionics course uses a classroom simulator, which is an integrated suite consisting of a mock-up of the cockpit, a flatboard panel (where students practice test procedures such as measuring resistances), and an interactive video display (where students simulate replacing parts). To use the simulator, the instructor specifies a fault to the computer and then (acting as the pilot) *debriefs* the students on the general problem (e.g., "There's a problem with the head-up display.") The students, who usually work in pairs, must then use their TOs and the simulator to troubleshoot the problem. The instructor sometimes assists the students if they are pursuing an unproductive path in their troubleshooting. After the students have found the fault, the instructor sometimes has them review the tests and replacements they made using the system schematic, thus allowing them to connect mental-model and procedures knowledge.

In the Avionics specialty, at least one aircraft is dedicated completely for use in training. To use the aircraft, laboratory time must be scheduled in advance in order to meet the needs of all classes requiring training of this type. Again, students usually work in pairs; however, the instructor is much more involved in the learning process. The instructor demonstrates the functions of different parts of the aircraft, how to perform operational checks, and how to interpret test results. The student then practices the skills just demonstrated, with frequent feedback (or coaching) from the instructor

Although the above description suggests that using simulators and aircraft are particularly valuable training methods, certain problems limit their effectiveness. The first problem is that the amount of time each student uses the simulator or aircraft is extremely limited. Before trainees get hands-on experience with the simulator, they must receive instruction in how to use it. Also, only one or two individuals may use the equipment at a time, as with the aircraft. So each individual student actually receives less than 21 hours experience with the simulator (4% of class time) during a 12 week course, and even less with the aircraft (a total of 4 days for the entire class). The second problem is that all the faults that can be simulated (using the current simulator) are common ones that can be solved by routine use of the TOs. Recall that 30% of flightline faults require technicians to go beyond the TOs. Thus, students do not get to use the simulator to practice solving these more difficult faults that require real problem solving. Instead, they use the simulator only to practice following the TOs, which may be a necessity given the limited time available.

Table 11
Methods of Evaluating Training Performance

Type of Evaluation	Technical School	FTD	OJT
Checklists	92%	86%	43%
Written Tests	100%	59%	26%
Part-task Trainer or Mock-Up	75%	27%	29%
Actual Equipment Performance	8%	100%	84%

As Table 11 indicates, Technical School students are most frequently evaluated by written tests and through use of checklists and part-task trainers or mock-ups (i.e., simulators). Progress Checks are used throughout the course of instruction, while written tests are used at the end of each block of instruction (Comprehensive Block Tests). The instructors follow a mastery-learning approach. If a student fails a written test, he or she works individually with the instructor to go over the material that should have been mastered. Students almost always pass the test on the second try.

Performance is typically certified/decertified by the instructor noting on AF Form 156 (Knowledge Progress Check) whether an individual has passed or failed relevant units of instruction. This form is completed and maintained by the instructor. The complete recordkeeping process typically includes the instructor recording student progress on AF Form 797, and students' final grades for each block of instruction on AF Form 156.

Field Training Detachment

We collected data on FTD classes for the Avionics, Electrical and Engineering, and Pneudraulics AFSs from the FTD school at Hill AFB. Most technicians are assigned to FTD classes as soon as they arrive at Hill AFB. Most FTD students fall into one of two categories: 1) new students from Technical School, or 2) those who have been Riveted. Despite the fact that students have prior technical training, little pre-instructional assessment is done (except for the Pneudraulics AFS), and instruction is pre-determined based on the course objectives and procedures outlined in the POIs.

The duration of the FTD courses are: Avionics - 12 days (72 hours), Environmental - 15 days (90 hours), and Pneudraulics - 12 days (72 hours). Each course focuses exclusively on F-16 subsystems relevant to that AFS.

The two questions we asked at the FTD school concerning course content were each broken down into two parts, dealing with two types of training. The first part focused on initial and upgrade training, which aim to increase a technician's skill level. The second part focused on qualification training, where the goal is to familiarize a technician with a different aircraft or subsystem. Since the course content for these two types of training was found to be very similar, the data for both of them are presented together. We also averaged across AFSs before presenting the data since there were only one or two respondents in each AFS. For the first question on course content, which focused on the reference tasks in Table 1, the most frequent

responses were given for system/subsystem knowledge (91%) and equipment/tool familiarization (82%). Other results are presented in Table 8, which shows that there is more emphasis on equipment/tool familiarization in FTD than in Technical School.

The second question on course content asked instructors what kind of troubleshooting knowledge they taught (with 1 indicating no coverage, 3 moderate coverage, and 5 extensive coverage). As Table 9 indicates, the results for this question are similar to those for the Technical School. FTD instructors are aware of and claim to teach all of the kinds of knowledge needed for expert troubleshooting. However, they place the greatest emphasis on mental-model knowledge (coverage of 4.7 for device knowledge and 5.0 for topographic/schematic knowledge).

As in the Technical School, a variety of teaching methods are used in the FTD school, as shown in Table 10. Again, the two most frequently used methods (averaging across training type and AFS) were formal training/lecture (100%), and demonstration and practice (95%). Thus, FTD instructors mix lecturing with some of the aspects of apprenticeship training, particularly modeling (demonstration) and practice.

Another similarity to Technical School is that simulators and aircraft are used in the FTD classes at Hill AFB, although the Avionics classes have no simulator. The simulators in FTD classes are used in a similar manner to those in Technical School. Students work in pairs. The simulator exercises focus on use of the TOs. One FTD instructor mentioned that using the simulators "teaches the students to trust the TOs." However, instructors sometimes ask students questions that require them to go beyond the procedures knowledge in TOs and access mental-model knowledge. For example, they may ask students to explain why a test yielded a certain result. Another point of similarity to Technical School is that students in the FTD spend very limited time on the simulators. At times, operational aircraft are used for training. However, this is sporadic and depends on the availability of aircraft and the reliability of the various systems, i.e., whether there is a problem to troubleshoot.

An interesting difference was found in the way simulators are used in the classes for different AFSs at the Hill AFB FTD. As mentioned before, the FTD Avionics classes have no simulator. The simulators for the Electrical and Environmental classes are used regularly. However, the simulator for the Pneudraulics classes, though available, is not used because it is out of date. Students in these classes are able to practice troubleshooting only in the rare case of a fault occurring when they are practicing an operational checkout on the training aircraft. This situation highlights the importance of simulators to classroom troubleshooting instruction, and the difficulty of updating expensive, high-fidelity simulators like the flatboards.

Table 11 shows that FTD students are most frequently evaluated via actual equipment performance (100%), and through the use of checklists (86%). These data suggest that in evaluating students, FTD instructors rely less on written tests and more on actual equipment performance, as compared to Technical School instructors. Typically, trainees are certified and decertified by the same method and forms for both initial/upgrade and qualification training. The method usually involves the trainee demonstrating proficiency through task performance. The instructor then manually records this status on various forms. AF Forms 325 and 623 are used as

well as documentation through the Core Automated Maintenance System (CAMS). These records are then carried through to the work center and maintained by the supervisor.

Logistics Support Training

Currently, at Hill AFB, the LST is conducting training similar to the FTD. Typically the LST supplements FTD training or provides the training that the FTD is not capable of providing. One of the main functions of the LST is to coordinate training between the workcenters and the FTD. This training has usually been requested or is required for the various workcenters; LST coordinates the scheduling of personnel for FTD courses. One LST instructor was interviewed, using the same questionnaire as for the FTD instructors. For this reason, and those mentioned above, data for this individual was combined with that of the FTD instructors.

On-the-Job-Training

We collected data on OJT for the Avionics, Electrical and Engineering, and Pneudraulics AFSs at Hill AFB. Before trainees begin OJT, their supervisors assess their knowledge and skills through verbal questioning, by observing their performance, and by checking their training history in their OJT folder. Based on this information, supervisors then determine what tasks or skills the trainee needs to learn and records this on the basic OJT record, AF Form 623. The tasks to be trained are taken primarily from the STS, which generally lists the skills and tasks needed for performance in a particular AFS. For example, the STS for *AFSC 452X2, Avionics* contains tasks such as "isolate malfunctions to fuel flow indicating system" and "use torque indicating devices". Tasks to be trained also include other maintenance-related tasks such as those peculiar to the local base and maintenance facility. OJT is administered on the flightline or off-flightline in hangers by supervisors or an assigned trainer.

The questionnaire data presented below is based on interviews conducted with supervisors. The data showed that the duration of OJT varies widely depending on the task, ranging from a few hours to months. A particular task is usually trained between one to three times per week; the duration of OJT sessions is between 1 and 8 hours.

As at the FTD, the questions concerning the content of OJT were asked for both initial/upgrade and qualification training and for the three AFSs noted above. Only the overall data is presented below. For the question on OJT content that focused on the reference tasks in Table 1, the most frequent responses were given to subtasks (81%), system/subsystem knowledge (81%), and equipment/tool familiarization (78%). The remainder of the results are shown in Table 8. Naturally enough, there is less emphasis on theoretical knowledge (system/subsystem knowledge) in OJT, and more emphasis on job-related tasks (subtasks) and procedures.

The second question on OJT content focused on what kind of troubleshooting knowledge is taught. The results , shown in Table 9, indicate that supervisors are aware of and give at least moderate coverage to all of the kinds of knowledge needed for expert troubleshooting.

The teaching methods used in OJT are different than those used in the classroom environments. The most frequently used methods are demonstration and practice (79%), and oversight and assistance (78%). Other responses are included in Table 10. Thus, as would be

expected, OJT emphasizes apprenticeship training (coaching/oversight, independent work with checks) more than Technical School or FTD training, while focusing less on formal methods like lecturing. In addition, Career Development Courses are used during OJT, although infrequently. A number of OJT supervisors stressed that the only way for trainees to learn many maintenance tasks was through hands-on experience. As an example of this, one respondent mentioned that a certain removal and replacement operation took about six hours the first time it was done, but could be done in 45 minutes with practice. In line with this emphasis on hands-on training, most OJT takes place on the flightline.

Evaluation of trainees performance during OJT takes place mostly on the flightline, as well. The results shown in Table 11 indicate that trainees are most frequently evaluated via actual equipment performance (84%), and through use of checklists (43%). Records of trainee progress are kept on Form 623. Typically, trainees are certified and decertified by the same methods and forms for both initial/upgrade and qualification training. The method usually involves the trainee demonstrating proficiency of STS objectives through task performance. The supervisor or trainer manually records this status on AF Forms 623 and 797, as well as in CAMS. These records are then maintained by the supervisor.

3.5.3 Summary of the Air Force Maintenance Training Process

We collected data in three training environments on the content of maintenance training (both general and specific to troubleshooting), and on training and evaluation methods. Concerning the general content of maintenance training (see Table 8), the Technical School teaches more system/subsystem knowledge than OJT, whereas OJT focuses on more detailed, installation-specific knowledge concerning specific subtasks and extenuating flightline procedures. FTD training falls between these two extremes. Instructors in all three training environments claim to teach all of the aspects of expert troubleshooting knowledge outlined in Table 2 (see Table 9), with a slight tendency towards emphasizing mental-model knowledge (i.e., specific device knowledge and schematics). As expected, the classroom environments, FTD and Technical School, emphasize formal training and evaluation methods such as lecturing and written tests (see Tables 10 and 11). OJT instructors, in contrast, focus more on apprenticeship-training methods such as independent work with oversight, and evaluate trainees more often via actual equipment performance.

It appears evident that timely evaluation and feedback during and after training is mostly dependent on the availability of the training supervisor or instructor. In the classroom settings, to receive feedback or evaluative information during training, the student must wait for the instructor's availability to answer questions or provide written test critiques. As for OJT, it appears that feedback and evaluative information is typically forthcoming with little delay. Remedial/review training in all environments typically consists of the supervisor or instructor going back over the material, task or skill that should have been mastered providing more in-depth information. Students are then re-evaluated for a second, and final, time.

Overall, this is not a surprising picture. The classroom environments use more formal training and evaluation methods, while OJT emphasizes hands-on training. We would like to stress that OJT instructors, and to some extent other instructors, believe very strongly in the value of hands-on training as the primary way to learn maintenance skills. However, the Technical

School and LST are the only training environments where aircraft are dedicated for purely training purposes, and even there hands-on training is extremely limited. For FTD and OJT, hands-on training is largely dependent on the availability of aircraft for training and on the reliability of the aircraft under study.

Where hands-on access to aircraft is limited, as in the classroom environments, instructors rely on simulators instead. The classroom instructors we interviewed saw the simulators as a very important part of instruction. Some instructors both at Technical School and FTD reported using the simulators for 30 to 35% of class time. Although individual students have limited access to the simulators because only two students can use a simulator at a time, this is still a significant portion of class time to devote to a single instructional method.

Technical School and FTD instructors use an apprenticeship-training approach with the simulators, allowing the students to work on the problem independently most of the time, but providing coaching when necessary. Instructors reported using the simulators in ways that would teach some of the problem-solving aspects of troubleshooting. For example, they asked students to explain why a troubleshooting test gave a certain result, and they had students locate the tests and replacements they made on a system schematic.

On the other hand, we noticed three significant problems that limit the usefulness of the current simulators in teaching the problem-solving aspects of troubleshooting. First, individual student access to the simulators is limited. Second, the flatboard simulators are hard to update and may not be used at all when they become outdated. Third, the current simulators only give students problems requiring routine use of the TOs.

3.5.4 Conclusions Concerning the Maintenance Training Process

Given our findings concerning maintenance training in the classroom and OJT environments, how might IMIS fit into these training environments? We will give a brief answer to this question here, and elaborate on these ideas in the concluding sections of this report. With respect to the classroom environments, using IMIS as a simulator holds considerable promise. Instructors value the current simulators and use them to teach problem-solving aspects of troubleshooting. IMIS simulators could be used in the classroom in addition to the flatboard simulators. This could alleviate the problems with the current simulators by giving students more access to simulators and allowing easy updating of simulators. In addition, IMIS simulators could give students problems requiring them to go beyond the TOs, while still using the intelligence of the IMIS DM to generate advice and feedback.

With respect to OJT, supervisors' and instructors' emphasis on hands-on training may limit the use of IMIS as a stand-alone simulator (i.e., apart from the aircraft). However, IMIS could be used as a training aid during actual maintenance activities. For example, if a trainee was repairing an aircraft without being pressed for time, IMIS could be put into a training mode where it would do such things as give more elaborate explanations for its choices and ask the trainee to predict the results of tests (Babiarz et al., 1989).

IV. IMPLICATIONS AND HYPOTHESES CONCERNING THE USE OF IMIS IN TRAINING

We now consider the implications of the Training-Situation-Analysis findings for how IMIS could be used in training, and suggest hypotheses for how IMIS may affect maintenance training. This section is structured in terms of two questions: 1) What kind of maintenance skills need to be trained? and 2) How can IMIS help train these skills? Specific hypotheses and implications are italicized in the text and listed in Table 12 at the end of this section.

4.1 Maintenance Training Needs

Concerning the type of maintenance skills to be trained, the findings on the current maintenance situation suggest that *technicians need training in: 1) the procedures knowledge contained in the TOs, and 2) the problem-solving knowledge needed to handle more difficult maintenance problems that require more than TO knowledge*. Most maintenance activities involve following pre-learned procedures. However, a substantial percentage of maintenance tasks (about 30% of the troubleshooting tasks at Hill AFB) require problem-solving knowledge beyond that contained in the TOs. Thus, *technicians need training in a wide variety of procedures (e.g., for equipment use, safety, recordkeeping, and troubleshooting)*. Also, in order to solve difficult troubleshooting problems, *technicians need explicit training in all of the different kinds of problem-solving knowledge used by expert troubleshooters, specifically: mental-model and symptom-fault-association knowledge, procedures, strategies, and coordination processes*.

4.2 How IMIS Can Assist in Maintenance Training

How, then, can IMIS help to train this diverse array of skills? In answering this question, we will consider each phase of the instructional process, including instructional design, instructional delivery, performance assessment, course management, and recordkeeping. We will present implications and hypotheses for each of these phases. For ease of presentation, we will focus on the instruction and assessment phases first.

4.2.1 Instructional Uses

We feel that *the most effective instructional use of IMIS is as a simulator*, and so we will concentrate on this use. There are two reasons for this focus. First, as a job aid, IMIS provides an interface (the PMA) that coordinates the entire maintenance process for the technician. Therefore, it would be very easy to implement realistic simulations using the PMA. Second, we feel that an IMIS simulator could be of significant help in training the most difficult skills technicians have to learn -- the problem-solving skills required for expert troubleshooting.
The apprenticeship-training literature suggests that coached practice is essential for learning complex problem-solving skills. OJT supervisors we interviewed also stressed the importance of practice in training maintenance skills. However, our data shows that in Technical School and FTD, students have very little chance to practice their skills on aircraft or simulators. As we will describe below, an IMIS simulator can provide extensive coached practice on troubleshooting problems, thus meeting a crucial training need.

Technicians also need training in many procedures that do not involve complex problem-solving. Furthermore, some of these procedures (e.g., removing and replacing components, using a multimeter, etc.) involve perceptual judgments that are hard to teach with a simulator. This is probably the reason why OJT supervisors favor hands-on aircraft training. We feel that IMIS would be less effective at training perceptual-based procedures, at least when it is used in a stand-alone mode. Some of the problems of teaching the perceptual aspects of maintenance can be solved by using an IMIS simulator with the aircraft or other, more realistic simulators. Therefore, we hypothesize that *an IMIS simulator can help teach maintenance skills in three different configurations: with the aircraft, with the flatboard simulators, and in a stand-alone configuration.*

When an aircraft is available for training, or, during OJT, when a trainee is working on an aircraft without time pressure, IMIS could be run in a training mode. This configuration would closely simulate flightline conditions, while providing more extensive coaching and data recording than is usually done by IMIS. When IMIS is used with the flatboards, the simulated instrument panels and video displays of aircraft components would help train the perceptual aspects of maintenance procedures. When IMIS is used in a stand-alone simulation, less realism would be provided. However, we feel that even in the stand-alone configuration, IMIS simulations could still provide effective maintenance training. One reason supporting this hypothesis is that some of the important aspects of troubleshooting skill, as outlined in Table 2, are cognitive, rather than perceptual, in nature. All of the types of troubleshooting knowledge in Table 2 include cognitive aspects that can be practiced in a simulator, away from the aircraft. Another reason for advocating off-aircraft simulators is the effectiveness of other computer-based troubleshooting simulators such as Sherlock (Lajoie & Lesgold, 1989).

Another advantage for using IMIS simulators in the three configurations described above is that this allows IMIS to be used in all Air Force training environments, Technical School, FTD, and OJT. *Using IMIS in multiple training contexts* follows one of the principles of apprenticeship training and *can increase transfer of training.*

The IMIS simulator we describe below focuses on teaching the problem-solving skills needed for expert troubleshooting. We focus on complex troubleshooting rather than other maintenance procedures for two reasons. First, teaching troubleshooting/problem-solving skills effectively is an important and unfulfilled need. Second, IMIS is in a better position to provide effective training in troubleshooting and problem solving than other training environments (e.g., authoring systems for computer-based training) because an IMIS training environment has access to the intelligence and knowledge in the DM and CDM.

We envision two levels of detail in an IMIS simulation. The first, which we call a *detailed simulation*, involves using the APS to augment the CDM with instructional information for each aircraft sub-system. This would use the full capabilities of IMIS to present maintenance training. However, authoring and updating the instructional information needed for a detailed simulation could prove expensive, especially if IMIS is used, as planned, for multiple aircraft. This led us to consider a second level of detail in simulation, what we call *generic simulation.* This would use minimal authoring of instructional materials, instead relying on knowledge and data already in the DM and the CDM. As we mentioned previously, in its job-aid capacity, IMIS contains

considerable knowledge about aircraft systems and maintenance processes. This information overlaps considerably with the knowledge used by expert human troubleshooters. As will be described below, we feel that the information currently in the CDM is enough to create a powerful simulation environment, if it is presented to students using appropriate instructional strategies. The generic simulation would require minimal authoring and updating beyond that needed to create the CDM. Once, initially developed, the generic simulation capability would be available at little extra cost for any aircraft with a CDM that can support IMIS job aiding. Of course, more detailed instructional information can be added to the generic simulation. However, since the generic simulation has the potential for being an inexpensive and effective instructional tool, we recommend developing it first, and will describe it first in this section.

In the following, we will outline the features that could be included in a generic IMIS simulation. To increase its instructional effectiveness, *this simulator should follow the principles of apprenticeship training (practice on realistic problems, coaching, fading, and collaborative learning).* The first feature, already discussed here, involves allowing students extensive problem-solving practice. However, if this practice is to be beneficial, the kind of problems students practice on is important. *Initially, students need to practice problems that involve routine use of the TOs*, as is done with the flatboard simulators. This will teach students procedures knowledge. *Later, students need to practice difficult problems that cannot be solved solely by the TOs.* This will require them to learn and use the other kinds of knowledge needed for expert troubleshooting. The capabilities of the IMIS DM potentially can allow it to solve some problems that the TOs alone cannot solve. However, as mentioned earlier, IMIS's ability to provide more accurate troubleshooting advice than the TOs has not yet been convincingly demonstrated. If this ability is demonstrated, it would be possible for an IMIS simulator to generate difficult ("beyond the TOs") problems and use the intelligence in the DM to coach students on these problems.

A second principle of cognitive apprenticeship involves coaching students as they solve problems. Coaching includes modeling expert problem-solving behavior and thinking, as well as giving feedback in the form of questions, hints, and reminders. We think that *IMIS can provide this kind of coaching, using the knowledge in the DM and the CDM. Furthermore, this coaching can help students learn most of the knowledge needed for expert troubleshooting (see Table 2.* For example, when the DM uses the half-split strategy to choose a test, the coach could describe this strategy to students. This is an example of modeling. Later, the simulation could give students the chance to choose their own tests and replacements, before seeing the DM's recommendations. At this point, the coach could determine whether the tests a student chose reflect use of half split. If they do not, the coach could remind the students of the strategy.

Another example of coaching involves teaching symptom-fault associations. When choosing a test, the coach could model symptom-fault-association knowledge by pointing out that a certain test was not chosen because it had a very high probability of passing (say, 90%)[3]. Thus, this test would not yield as much information as a test that has closer to a 50% probability of passing. Later, when students choose their own tests, the coach could ask them to enter the expected probabilities that these tests will pass, and correct them if they are wrong.

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[3] This type of modeling was implemented in a prototype IMIS instructional simulation developed by Babiarz, et al. (1989).

These two examples reflect a general instructional strategy of first having the DM model appropriate troubleshooting knowledge as the student is solving a problem. Later, the student is given more responsibility for decisions during problem solving (e.g., choosing their own tests). At this point, through questions and feedback, the coach focuses the students on the appropriate troubleshooting knowledge for the current decision. This instructional strategy could be used to instruct most of the knowledge in Table 2, in particular, symptom-fault associations, procedures, strategies, and some coordination processes. As mentioned earlier, instructing students in mental-model knowledge in a generic simulation (i.e., without adding information to the CDM) would be difficult, since the CDM contains little mental-model knowledge.

The coaching described here implements some aspects of an ITS, without using a student model. Instead of basing its response on a model of student abilities, the coach determines its response by comparing the student's and the expert's (i.e., the DM's) performance. Newman (1989) has described a similar ITS that does not involve student modeling. In the assessment section, below, we will outline how some student modeling capabilities could be incorporated in the IMIS generic simulation.

The effectiveness of the coaching described above depends, to some extent, on whether IMIS can solve some of the difficult troubleshooting problems that the TOs cannot solve. If IMIS cannot do this, its coaching will be less effective, although not completely ineffective. Some of the coaching described above (e.g., modeling troubleshooting knowledge and skills) might still help students learn, even if IMIS is not able to solve some problems. The extent to which the effectiveness of IMIS's coaching depends on the accuracy of its troubleshooting advice will be investigated further in the next phase of this project.

A third principle of cognitive apprenticeship is fading, whereby the coach withdraws support as the student becomes more proficient. *A simple way to implement fading would be to have different levels of coaching in the generic simulation.* The novice level would focus on the coach modeling and explaining the troubleshooting process, with the students having little input into the decision making. An intermediate level would allow students to have more input into decisions during problem solving, but the coach would ask questions and give feedback to ensure they were using the correct knowledge in making those decisions. The expert level would provide no coaching, allowing the students to make troubleshooting decisions as if they were using IMIS on the flightline. The instructor or the students could choose which level of coaching to use for a particular problem.

An even more effective way to implement fading would involve some student modeling. As will be described in the assessment section, a diagnostic capability could be added to the generic simulation, giving it the ability, for example, to evaluate and remember how well a student knows the half-split strategy. Given this information in a student model, the coach could determine what kind of coaching to give concerning this strategy. A student modeling capability would allow more tailoring of instruction to individual needs than simply having novice, intermediate, and expert simulations, but would be more costly to develop.

A fourth principle of cognitive apprenticeship is to encourage collaborative problem-solving among students. This principle is already being followed in the use of the flatboard simulators in

Technical School and the FTD. Students solve problems in pairs with the instructor occasionally offering assistance or coaching. *We recommend that this practice continue with IMIS simulators. In addition, other forms of collaboration are possible* (Katz & Lesgold, in press). For example, students could pose problems for each other. Or, a student's performance on a troubleshooting problem could be recorded using IMIS's recording capability and later replayed for discussion by other students or the instructor. With appropriate guidance by an instructor, a classroom or learning laboratory with a number of IMIS simulators could become a rich environment for student interaction and learning.

All of the instructional features described above could be implemented in a generic IMIS simulator that uses just the CDM knowledge needed for job aiding. The detailed simulator could build on these features in a number of ways. For example, the APS could be used to add mental-model information to the CDM so that students could be coached in this kind of knowledge. Also, videodisk or virtual-reality capabilities could be added to the simulator. This would be of particular help in teaching students some of the perceptual aspects of maintenance activities. For example, when removing and replacing a component as part of a troubleshooting problem, students could use the videodisk screen to see what the component looks like and where it is located on the aircraft. A videodisk capability like this is already implemented for the flatboard simulators used in Technical School and the FTD.

4.2.2 Assessment Uses

An IMIS simulator could perform two types of student assessment: 1) detailed diagnosis of students' strengths and weaknesses for use by an instructor, and 2) more general evaluation of student readiness for course advancement or particular work tasks. We will describe the diagnostic assessment first.

As we mentioned earlier, *a generic IMIS simulator could do some simple student modeling.* For example, the simulator could obtain information about a student's use of the half-split strategy by having the student choose troubleshooting tests and replacements before seeing the DM's recommendations (e.g., as in the intermediate level simulator described above). Using information available in the CDM, the simulator could immediately evaluate each proposed test and replacement in terms of how well it conformed to the half-split strategy. This information could be used to update a variable in a student model representing knowledge of this strategy. A similar approach could be used to model student knowledge of other strategies (e.g., elimination), symptom-fault associations, and some coordination processes. This modeling could be done as part of the generic IMIS simulator, since it relies on knowledge currently in the CDM. Only limited mental-model knowledge could be modeled using information currently in the CDM.

The information in a student model could be used in two ways. First, the simulator could use this information to tailor its coaching to individual student needs, as students work on problems. This would involve implementing the capabilities of a full-fledged ITS. We think this is possible, given the current configuration of the DM and the CDM, although the student model would be limited, in that it would not represent all the knowledge required for expert performance. *A second, and less costly, way to use the detailed diagnostic information in a student model would be to print out a report describing a student's knowledge.* The instructor could use this report to plan instruction, and/or students could use it to plan their studying.

A second kind of assessment that could be provided by an IMIS simulator is a general evaluation of student readiness for course advancement or job performance. For example, a supervisor could assign a student to practice a certain troubleshooting task on the simulator. When the student is ready, he or she could take a test run through the simulator on that task. *The simulator could then print out a report comparing the student and the simulated expert (i.e., the DM)* on information such as the number of tests and component replacements performed and simulated maintenance time. This information could help the supervisor decide whether the student was ready to perform this task on the flightline. Such a tool in the Technical School could enable students to achieve higher proficiency levels prior to graduation or to reduce the time required to achieve current proficiency levels.

The above assessment functions could be performed by a generic IMIS simulator, with minimal changes to the CDM. A more detailed simulation could focus on functions such as assessing students' mental-model knowledge.

To summarize our ideas concerning an IMIS simulator, *a generic IMIS simulator could be developed with the instructional and assessment capabilities described above (i.e., extended problem-solving practice, coaching, fading, collaboration, assessment reports, and limited student modeling). This simulator could use the intelligence and information currently available in the DM and CDM, and thus would not require extensive and costly authoring of instructional materials. The simulator would follow effective principles of instruction (cognitive apprenticeship) and implement some features of an ITS. We hypothesize that such a simulator would have a number of beneficial effects, including:*

- *increasing student practice of maintenance tasks;*
- *increasing student knowledge of the problem-solving skills necessary for expert troubleshooting (cf., Table 2);*
- *reducing training time without requiring additional instructors; and/or increasing students' proficiency levels.*

However, some of the troubleshooting processes used by the current version of IMIS, particularly those involving mental-model knowledge and coordination processes, are significantly different from those used by humans. Therefore, *in its current state, IMIS probably could not be used to train advanced troubleshooting skills* (e.g., for skill-level 7 technicians). *IMIS currently offers more potential for training novice technicians*, although even for training novices, the addition of some mental-model knowledge to IMIS is recommended.

Using the generic IMIS simulator as a base, a more detailed simulator could be developed with increased use of mental-model knowledge and video-based output (video or virtual reality).

4.2.3 Course Management and Recordkeeping

The scenario just discussed -- of students using a simulator to practice and take tests on specific maintenance tasks, with instructors receiving evaluation reports -- brings up issues of course management, task proficiency, and recordkeeping. Concerning course management, IMIS could be the central tool in a Personalized System of Instruction course (Maddux, Johnson &

Willis, 1992). In this system, each student could be assigned an individualized set of maintenance tasks to master. They could practice these tasks in a learning laboratory, which has IMIS simulators, TOs, and other reference materials, as well as an instructor to serve as a resource person. Whenever students used the IMIS simulator to take tests on particular maintenance tasks, IMIS could record an evaluation of their performance. It could also keep track of students progress through their assigned tasks. If this laboratory were in an OJT setting, the data concerning trainee task proficiency could be recorded on an on-line version of the OJT progress form (AF Form 623), or directly in BTS . This type of laboratory would allow self-paced learning and could be used for initial or remedial learning of maintenance tasks.

Through its function of recording and managing student training data, IMIS can link up with other automated training systems, such as the Advanced Training System (ATS) for use in the Technical Schools or the Base Training System (BTS) for use on the job. By tracking student performance on various tasks while in Technical School, IMIS could feed highly accurate performance data to ATS for use in evaluation of students. IMIS data could be used to generate reports of overall student proficiency by STS task, or to produce specific training deficiency reports due to the lack of some training resource. The same kind of highly accurate, task specific qualification information could be automatically fed into BTS by IMIS. This would alleviate the need for the OJT supervisor to record this information manually or enter it into a computerized system. All training status information would be centrally stored on-line where higher echelon personnel would have access to it. This includes information such as which maintenance personnel are fully qualified and ready for deployment, which personnel have minor deficiencies that can be quickly remedied, and what tasks need remediation.

4.2.4 Instructional Design

Instructional design and authoring would be necessary to develop the instructional materials (e.g., materials to teach mental-model knowledge) for the detailed IMIS simulator, as discussed above. The current IMIS system for authoring is the APS. It is possible that the capabilities of the authoring/presentation software (APS) may be augmented by linking it with the BTS, ATS, or Automated Instructional Design Advisor (AIDA) to serve the purpose of designing, developing, delivering, and evaluating maintenance training. Further research will be needed to assess efforts at integrating or interfacing any of these systems. However, we currently visualize these interfaces occurring as shown in Figure 3.

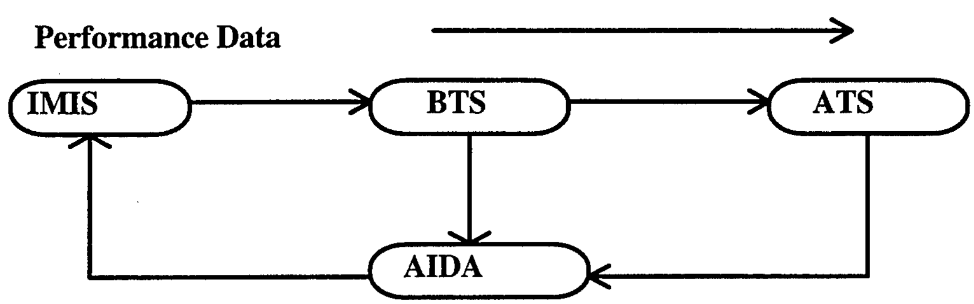

Figure 3. Authoring scenario based on proposed links between systems.

The authoring scenario depicted in Figure 3. shows that performance data from IMIS could be transferred though BTS to ATS. Information from these systems would then be used in

identifying tasks which need training support. Such data, in conjunction with expert advice from AIDA could then be used to author instruction for presentation on IMIS either through the PMA or some stand alone computer with IMIS data available.

Table 12
Final Hypotheses

Maintenance Training Needs

Technicians need training in: 1) the procedures knowledge contained in the TOs, and 2) the problem-solving knowledge needed to handle the more difficult maintenance problems that require more than TO knowledge.

Technicians need training in a wide variety of procedures (e.g., for equipment use, safety, recordkeeping, and troubleshooting).

Technicians need explicit training in all of the different kinds of knowledge used by expert troubleshooters, spcifically: mental-model and symptom-fault-association knowledge, procedures, strategies, and coordination processes.

How IMIS Can Assist in Maintenance Training

Instructional Uses

The most effective instructional use of IMIS is as a simulator

An IMIS simulator can effectively teach maintenance skills in three different configurations: with the aircraft, with the flatboard simulators, and stand alone. This would allow IMIS to be used in multiple training contexts (Technical School, FTD, and OJT), which can increase transfer of training.

A generic IMIS simulator could be developed with both instructional and assessment capabilities, including extended problem-solving practice, coaching, fading, collaboration, assessment reports, and limited student modeling. This simulator could use the intelligence and information currently available in the DM and CDM, and thus would not require extensive and costly authoring of instructional materials.

The generic simulator should follow principles of apprenticeship training (extensive practice on realistic problems, coaching, fading, collaborative learning) and can include some features of an ITS.

Practice: Initially, students need to use a simulator to practice problems that involve routine use of the TOs, Later, students need to practice difficult problems that cannot be solved solely by the TOs.

Coaching: An IMIS simulator can provide effective coaching (modeling, questioning, hinting, reminding) using just the knowledge in the current DM and CDM. However, the effectiveness of IMIS's coaching may be diminished if it cannot give accurate advice on difficult troubleshooting problems that the TOs cannot solve.

Fading: Fading, withdrawing support as the student progresses, can be implemented by having different levels of coaching (e.g., novice, intermediate, expert) or by doing limited student modeling.

Collaborative learning: The collaborative learning with simulators already practiced in the Technical School and FTD should be continued and extended with IMIS simulators.

Assessment Uses

A generic IMIS simulator could perform two types of student assessment: 1) detailed diagnosis of students' strengths and weaknesses for use by an instructor, and 2) more general evaluation of student readiness for course advancement or particular work tasks.

A generic IMIS simulator could do some simple student modeling. It could also create reports containing information concerning student knowledge (e.g., knowledge of troubleshooting strategies) and/or data on how well students performed specific maintenance tasks.

Table 12. continued

<u>**Summary of Instructional and Assessment Uses**</u> A generic simulator using the instructional and assessment features described above would have some or all of the following beneficial effects: • increasing student practice of maintenance tasks; • reducing training time without requiring more instructors; • increasing student proficiency levels; and • increasing student knowledge of the problem-solving skills necessary for expert troubleshooting (cf., Table 2). Through its function of recording and managing student training data, IMIS can link up with other automated training systems, such as the Base Training System (BTS). IMIS will relate to BTS by improving upon the integration of training records (status information on personnel). All training status information would be centrally stored on-line where relevant personnel would have access to it. <u>**Instructional Design**</u> It is possible that the capabilities of the APS may be augmented by linking it with the Automated Instructional Design Advisor (AIDA) or the Advanced Training System (ATS) to serve the purpose of designing, developing, delivering, and evaluating maintenance training.

V. CONCLUSIONS AND RECOMMENDATIONS

This report describes our work on part of a project to analyze how IMIS can be used in maintenance training. In this part of the project, our goal was to analyze the current Air Force maintenance training environment and develop recommendations and hypotheses for how IMIS could be used in this environment. In order to do this, we also analyzed the current Air Force maintenance process and the capabilities of IMIS. We collected data on maintenance and the maintenance training process through structured interviews at Technical School (Lowry AFB), FTD (Hill AFB), and OJT (Hill AFB, Kelly AFB) sites. We also investigated IMIS's capabilities by attending IMIS demonstrations and examining relevant literature.

Our data on the maintenance process suggests that Air Force maintenance technicians need training in a large number of procedures. This need is being met fairly well at the current time through the existing training environment and the system of TOs. On the other hand, the Air Force also has a critical need to train technicians who can use the variety of problem-solving knowledge required for expert troubleshooting. Many of the maintenance personnel we interviewed suggested that, currently, this need is not being met.

Our review of the training literature suggests that cognitive apprenticeship training is a very effective way to teach the complex problem-solving skills needed for expert troubleshooting. This approach involves realistic problem-solving practice, coaching, fading, and collaborative learning. Our data on the maintenance training process showed that some aspects of apprenticeship training are used in Air Force OJT, where instructors rely on demonstration, coaching, and practice on the flightline or with training aircraft. Training in the classroom environments (Technical School and FTD) relies more on formal methods such as lectures and written tests. However, even in the classroom environments, instructors give students realistic practice as much as possible, using actual aircraft or maintenance simulators. A major limitation

of the current training system is that students do not receive enough practice on maintenance tasks, especially difficult troubleshooting tasks that require problem-solving. This limitation is especially evident in the classroom environments.

So far, we have identified a need for troubleshooting/problem-solving training, a method for providing that training via coached practice, and a problem, in that Air Force maintenance technicians do not receive enough problem-solving practice. We feel that IMIS can provide the solution to this training problem if it is used as a simulator that has access to the intelligence and information in the DM and the CDM. We described two kinds of IMIS simulators, a generic simulator that uses primarily the knowledge currently in the DM and CDM, and a detailed simulator that uses enhanced output capability (e.g., video) and authoring of additional knowledge into the CDM.

The generic simulator would use all the principles of apprenticeship training and explicitly teach most of the types of knowledge required for expert troubleshooting. It would also be a relatively low-cost environment, since little authoring and updating of instructional materials would be needed. The key factors that currently limit IMIS's usefulness in providing training are the lack of human-like mental-model knowledge and coordination processes in the DM and CDM. Some of this missing troubleshooting knowledge possible could be added to the detailed IMIS simulator. Also, a videodisk capability would allow the detailed simulator to train procedures with significant perceptual components, such as removing and replacing parts.

We feel that both of these IMIS simulators would provide powerful training environments that would effectively teach maintenance skills, including critical troubleshooting skills. Also, these simulators probably would easily fit into the current training practices in the Technical Schools and FTD classrooms, given the value placed on simulators in these environments. We have also outlined ways in which IMIS could fit into the OJT training environment. In conclusion, the training capability of IMIS has the potential of being one of the most impressive aspects of this system.

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APPENDIX A: INTERVIEW QUESTIONNAIRE

(As mentioned previously all questionnaires are variations of one another. Therefore, in this Appendix we have included the most inclusive questionnaire; all others are subsets.)

TRAINING SITUATION AND TASK EVALUATION QUESTIONNAIRE

This questionnaire was developed for use by Mei Technology analysts in the conduct of structured interviews and is being administered in conjunction with research that is currently underway at Wright-Patterson AFB, Ohio and Brooks AFB, Texas. This questionnaire has a dual data gathering purpose. First, it will assess the current training situation for flightline maintenance performance and training personnel in order to analyze the capabilities of IMIS to support maintenance training. Second, it will assess the current maintenance training provided in the formal technical school and help determine the potential impact of introducing IMIS into that environment. Your expertise in this area is greatly appreciated and your answers are strictly confidential.

Thank you for your time and cooperation.

PERSONNEL PROFILE FOR MAINTENANCE SUPERVISORS

Please complete the following information:

AFSC: ______________________________ SKILL LEVEL: ____________________

Job Title: ______________________________

Approximately how long have you been in the Air Force? ______________________________

Approximately how long have you been in the maintenance career field? ____________________

Approximately how long have you been in this specialty? ______________________________

Approximately how long have you been in your current work center? ____________________

Approximately how long have you been a maintenance supervisor? ____________________

Approximately how long have you been an OJT trainer? ______________________________

Please describe the type (i.e., actual hands-on, knowledge of operations, etc.) and extent of IMIS experience you have had ____

TASK AND TRAINING INFORMATION

TASK # ____________:

In reference to the above stated task, please answer the following questions:

1. Is this task currently being performed in this specialty and this workcenter?
   ______ no (continue with question # 2)
   ______ yes (go to question # 3)

2. Please indicate with a check mark which of the following is true:
   ______The task has been combined with another. (please explain) ____________________
   ____
   ______The task has been split into two or more tasks. (please explain) ________________
   ____
   ______The task is no longer being performed. (Thank you for your time; the questionnaire for this task is complete).

3. Is training provided for this task?
   ______ yes (continue with question # 4)
   ______ no (go to question # 17)

4. How is the trainee pre-assessed for instruction? ______________________________
   ____

5. How is training conducted for this task? (please indicate all those that apply)

Initial/Upgrade Training:	Qualification Training:
______ On the Job Training	______ OJT
______ Technical School	______ Technical School
______ Field Training Detachment	______ FTD
______ Aircraft Maint. Qual. Program	______ AMQP
______ Career Development Course	______ CDC

6. Who typically conducts the training on this task? (please indicate all those that apply)

Initial/Upgrade Training:	Qualification Training:
______ supervisor	______ supervisor
______ trainer (non-supervisory)	______ trainer (non-supervisory)
______ FTD instructor	______ FTD instructor
______ journeyman technician	______ journeyman technician
______ Technical School instructor	______ Technical School instructor

   ______ other (please explain) ____

<u>TASK AND TRAINING INFORMATION (continued)</u>

7a. What things are taught during *initial/upgrade* training? (please indicate all those that apply)
   ______ subtasks____

______ equipment/tool familiarization ______
______ extenuating flightline procedures ______
______ administrative procedures ______
______ system/subsystem knowledge ______
______ other ______

7b. What things are taught during *qualification* training? (please indicate all those that apply)
______ subtasks ______

______ equipment/tool familiarization ______
______ extenuating flightline procedures ______
______ administrative procedures ______
______ system/subsystem knowledge ______
______ other ______

8. What methods are used for conducting the training? (please indicate all that apply)

Initial/Upgrade Training:	Qualification Training:
______ demonstration/practice	______ demonstration/practice
______ oversight and assistance	______ oversight and assistance
______ formal training	______ formal training
______ independent work with checks	______ independent work with checks
______ Computer Based Training	______ CBT

______ other (please explain) ______

9. What parts of the training are self-paced? ______

10. What is the approximate average duration (from beginning to end) of training on this task?
Initial/Upgrade: ______
Qualification: ______

11. How often is training provided (e.g., every day, once a week, every two weeks, etc.)?
Initial/Upgrade: ______
Qualification: ______

12. Approximately how long is each training session?
Initial/Upgrade: ______
Qualification: ______

TASK AND TRAINING INFORMATION (continued)

13. How are students evaluated? (please indicate all that apply)

Initial/Upgrade Training:	Qualification Training:
______ through use of a checklist	______ through use of a checklist
______ written tests	______ written tests

______ part task trainers or mock-ups ______ part task trainers or mock-ups
______ actual equipment performance ______ actual equipment performance
______ other: ____________ ______ other: ____________

14. Who conducts the evaluation? (please indicate all that apply)

Initial/Upgrade Training:	Qualification Training:
______ supervisor	______ supervisor
______ Quality Control personnel	______ Quality Control personnel
______ other: ____________	______ other: ____________

15. How is task performance certified/decertified, and by whom?
Initial/Upgrade: ______________________________
____
Qualification: ______________________________
____

16. Please describe the recordkeeping process. ______________________________
____

TASK CHARACTERISTICS

17. Please answer the following questions with "y" for "yes" and "n" for "no":

______ Are the task performance requirements hard to communicate through printed words?

______ Would the performance of this task benefit from the use of graphs, charts, tables, or illustrations?

______ Does the learning of this task prepare the individual to perform a subsequent task?

______ Does the performance of this task require the verification of readings and tolerances?

______ Does the performance of this task require high accuracy and completeness due to the presence of high risk or danger?

______ Is this task too complex to learn on the job?

TASK CHARACTERISTICS (continued)

______ Does this task require long and complex behavioral sequences?

______ Does this task require many decisions?

______ Is this task performed in a fixed sequence or order?

_______ Is this task so new or undefined that the detailed steps are hard to master?

_______ Does this task consist of steps performed in rapid succession?

_______ Does this task require rapid response such that there is no time to refer to printed instruction?

_______ Is this a lengthy task that requires attention to detail?

_______ Is this task frequently performed (perhaps several times a day)?

_______ Is this task performed by a large number of the individuals in this specialty?

_______ Does this task need much practice for acceptable performance?

_______ Is reference to printed material disruptive to performance of this task?

_______ Does the performance of this task require making decisions based on an awareness of numerous existing conditions?

_______ Does the performance of this task require branching logic such as that found in diagnostic decision aids?

_______ Does the performance of this task require team effort?

_______ Does the performance of this task require only one person to perform?

_______ Are the consequences of task performance errors serious, such as with emergency procedures?

_______ Is an occasional performance error likely to result in equipment damage?

_______ Is the risk of damage to personnel or equipment high?

_______ Is the task costly to train?

_______ Are both training time and budget limited?

<u>TASK CHARACTERISTICS (continued)</u>

_______ Is memorization (of steps involved) required for performance of this task?

_______ Can the task be mentally rehearsed before it needs to be performed?

_______ Is the task likely to change frequently?

_______ Is the performance method likely to change?

______ Is maintenance equipment easily accessible?

______ Is maintenance equipment usually available?

______ Does the task require detailed procedures to properly access equipment?

SUPPLEMENTARY QUESTIONNAIRE: MAINTENANCE SUPERVISORS

Troubleshooting Information : The information requested for this questionnaire is not specific to any task in particular, rather it concerns troubleshooting in general.

A. *Types of faults encountered.*

We are interested in receiving information that is specific to troubleshooting tasks performed by the maintenance technicians you supervise. By troubleshooting, we mean diagnosing and fixing faults in a system. We will define two types of faults, "technical-order" faults, and "problem-solving" faults.

Technical-order faults can be handled simply by following the proper technical orders and applying basic knowledge about the system and about how to perform tests and repairs. The key characteristic of a technical-order fault is that the technician does not have to make any major decisions about the what tests or repairs to make or how to sequence tests or repairs. All of these decisions are made by the technical orders.

In problem-solving faults, on the other hand, the technical orders do not provide enough information to diagnose or repair the fault. Here the technician must make major decisions about what tests or repairs to make and/or how to sequence these tests and repairs.

1. Estimate the percentage of technical-order faults that your maintenance technicians encounter _____%

2. Estimate the percentage of problem-solving faults that your maintenance technicians encounter _____%

B. *Current troubleshooting practices.*

We have listed a number of approaches to troubleshooting below. For the average maintenance technician you supervise, please estimate the percentage of troubleshooting tasks performed using each of these approaches. Since technicians may use more than one approach on a single problem, the percentages do not have to add to 100%.

On what percent of the problems encountered, does the average technician:

a. follow technical orders? ______%

b. recall how he/she solved the same problem before and use this procedure?
______%

c. recall how he/she solved a similar problem before and use this as an analogy or example? ______%

d. ask co-workers for help? ______%

e. use troubleshooting strategies? ______%
examples of strategies:
-working backwards from the bad output or symptom
-eliminating components you know to be working
-half split (i.e., choosing a test that will eliminate about half of the possibly faulty components)

f. other approaches? _____% (Please explain) ______________________________
____
____

C. *How troubleshooting is taught.*

1. The following are different kinds of knowledge that are used in troubleshooting (diagnosis and repair). Use the 5-point scale shown below to indicate how extensively each kind of knowledge is covered in training.

no coverage		moderate coverage		extensive coverage
1	2	3	4	5

a. ______ device, or system, knowledge (i.e., information that is specific to various aircraft subsystems that are maintained)

b. ______ procedural knowledge (i.e., specific steps involved in diagnosis and repair of the aircraft)

c. ______ schematics or visual maps of how the various parts of the sub-system relate and fit together, and how they fit into the scheme of the entire aircraft

d. ______ symptom-fault associations (i.e., how to find frequently occurring faults at a glance by recognizing the pattern of symptoms, or bad outputs, caused by the faults)

e. ______ troubleshooting strategies (e.g., half-split; work backwards from the bad output or symptom; eliminate components that are known to be working)

f. ______ specific test procedures (e.g., using an oscilloscope)

g. ______ time and cost considerations (i.e., advantages and disadvantages of performing various tests and repairs)

h. ______ other: ____
____

2. What methods are used to teach troubleshooting? (please check all that apply)

a. ______ demonstration/practice

b. ______ oversight and assistance

c. ______ formal training

d. ______ independent work with checks

e. ______ CAI/CBT

f. ______ other (please explain) ______________________________________
____
____

3. Approximately what percentage of training focuses explicitly on the aspects of troubleshooting that require problem solving (e.g., using strategies such as half split and elimination, considering both the costs and the information gained when deciding on a test)? _____%

4. Approximately what percentage of training focuses explicitly on aspects of troubleshooting that do not require problem solving (e.g., following technical orders, how to use test equipment and make repairs)? _____%

IMIS Information

D. *Effects of IMIS on performance and training.*

Given what you know, or have been told about IMIS:

1. In what ways do you feel the introduction of IMIS to flightline maintenance will impact the technician's performance of his/her job? ______________________
____
____
____
____

2. In what ways do you feel the availability of this system will affect maintenance ____
____
____
____
____

APPENDIX B: PREREQUISITES FOR SELECTING INTERVIEWEES

Personnel Type	Selection Criteria	Conditions
Maintenance Supervisor	1. Three first line supervisors to be interviewed in each of the three AFSs (total of nine)	Desired Number
	2. Each supervisor to have knowledge of current flightline maintenance training procedures, to include conduct of training, evaluation, and record keeping.	Required
	3. Each supervisor to have general knowledge of IMIS operations as they relate to flightline procedures.	Desired
	4. Each supervisor to have general knowledge of IMIS operations as they relate to specific task performance of those tasks chosen in each AFS.	Desired
	5. Each supervisor to be skilled in the performance and training of the tasks chosen in each AFS.	Required
Maintenance Technicians	1. Three technicians to be interviewed in each of the three AFSs (total of nine)	Desired Number
	2. Each technician to have general knowledge of IMIS operations as they relate to the flightline maintenance process.	Desired
	3. Each technician to have specific knowledge and experience with IMIS operations as they relate to specific task performance for the chosen tasks in each AFS.	Desired
	4. Each technician to be skilled in the performance of the chosen tasks in each AFS.	Required
Maintenance Training Manager(s)	1. One or more maintenance training manager(s) having training management responsibility for each of the three AFSs.	Required
	2. Each maintenance training manager to have knowledge of the flightline maintenance training and record keeping process.	Required

Personnel Type	Selection Criteria	Conditions
Field Training Detachment (FTD) Instructor(s)	1. At least one Field Training Detachment Instructor in each of the three AFSs who has current experience formally teaching associated tasks	Required
	2. Each FTD instructor to have knowledge of current FTD maintenance training/instructional procedures to include conduct of instruction, evaluation, and record keeping	Required
	3. Each FTD instructor to have general knowledge of the flightline maintenance process to include postflight, debriefing, scheduling, troubleshooting, parts ordering, repair, and status reporting.	Desired
	4. Each FTD instructor to be skilled in the performance and training of the chosen tasks in their AFS.	Preferred
Technical Training Instructor (s)	1. At least one instructor in each of the three AFSs who has current experience formally teaching the associated tasks.	Required
	2. Each instructor to have knowledge of current technical school maintenance instructional procedures to include conduct of instruction, evaluation, and record keeping.	Desired
	3. Each instructor to have general knowledge of the flightline maintenance process to include postflight, debriefing, scheduling, troubleshooting, parts ordering, repair, and status reporting.	Desired
	4. Each instructor to be skilled in the performance and training of the tasks for their AFS.	Preferred
Course Supervisor(s)	1. At least one course supervisor to have managerial and administrative responsibility for AFS courses which teach the chosen tasks for that specialty.	Required
	2. Each course supervisor to have knowledge of the course development process.	Required